B.R. Wells

Arkansas Rice Research Studies 2014

R.J. Norman and K.A.K. Moldenhauer, editors

UofA DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION

August 2015 Research Series 626

This publication is available on the Internet at http://arkansasagnews.uark.edu/1356.htm

Cover Photo: Members of the Rice Agronomy and Soil Fertility team apply urea fertilizer to nitrogen management research plots near Stuttgart, Ark. Photo credit: Jarrod Hardke, University of Arkansas System Division of Agriculture.

Layout and editing by Marci A. Milus
Technical editing and cover design by Gail Halleck

Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture. Clarence E. Watson, Associate Vice-President for Agriculture–Research and Director, AAES. MG350CS5/CS6.

ISSN:1941-2177 CODEN:AKAMA6

B.R. Wells

ARKANSAS RICE Research Studies 2014

R.J. Norman and K.A.K. Moldenhauer, editors

University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

Bobby R. Wells

Bobby R. Wells was born July 30, 1934, at Wickliffe, Ky. He received his B.S. degree in agriculture from Murray State University in 1959, his M.S. degree in agronomy from the University of Arkansas in 1961, and his Ph.D. in soils from the University of Missouri in 1964. Wells joined the faculty of the University of Arkansas in 1966 after two years as an assistant professor at Murray State University. He spent his first 16 years at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. In 1982, he moved to the University of Arkansas Department of Agronomy in Fayetteville.

Wells was a world-renowned expert on rice production with special emphasis on rice nutrition and soil fertility. He was very active in the Rice Technical Working Group (RTWG), for which he served on several committees, chaired and/or moderated Rice Culture sections at the meetings, and was a past secretary and chairman of the RTWG. He loved being a professor and was an outstanding teacher and a mentor to numerous graduate students. Wells developed an upper-level course in rice production and taught it for many years. He was appointed head of the Department of Agronomy in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, service, and teaching.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993) and was awarded, posthumously, the Distinguished Service Award from the RTWG (1998).

Wells edited this series when it was titled *Arkansas Rice Research Studies* from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the *B.R. Wells Rice Research Studies* in his memory starting with the 1996 publication.

FOREWORD

Research reports contained in this publication may represent preliminary or only a single year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off program. This publication also contains research funded by industry, federal, and state agencies.

Use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agricultural Research Service. For further information about any author, contact Division of Agriculture Communications, (479) 575-5647.

ACKNOWLEDGMENTS

Most of the research results in this publication were made possible through funding provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. We express sincere appreciation to the farmers and to the members of the Arkansas Rice Research and Promotion Board for their vital financial support of these programs.

CONTENTS

OVERVIEW AND VERIFICATION

Trends in Arkansas Rice Production, 2014
J.T. Hardke..11

2014 Rice Research Verification Program
R.S. Mazzanti, R. Baker, J.T. Hardke, K.B Watkins, and R. Mane...................... 23

BREEDING, GENETICS, AND PHYSIOLOGY

Molecular Analysis for the Development of Rice Varieties
V.A. Boyett, V.I. Thompson, V.L. Booth, K.A.K. Moldenhauer, G.L. Berger, X. Sha, D.K.A. Wisdom, J.M Bulloch, and H. Sater 44

Screening for Rice Blast Resistance of Uniform Rice Regional Nursery Varieties
C. Feng, F. Rotich, and J.C. Correll.. 50

Rice Breeding and Pathology Technical Support
C.D. Kelsey, S.B. Belmar, K.A.K. Moldenhauer, and Y.A. Wamishe.................. 56

Breeding and Evaluation for Improved Rice Varieties—the Arkansas Rice Breeding and Development Program
K.A.K. Moldenhauer, X, Sha, G.L. Berger, J. Hardke, Y. Wamishe, C.E. Wilson Jr., R.J. Norman, M.M. Blocker, D.K.A. Wisdom, D.L. McCarty, V.A. Boyett, B.A. Beaty, J.M. Bulloch, D.L. Frizzell, C. Kelsey, S. Belmar, H. Sater, V. Booth, and V. Thompson............................... 63

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South
X. Sha, K.A.K. Moldenhauer, B.A. Beaty, J.M. Bulloch, D.K.A. Wisdom, M.M. Blocker, D.L. McCarty, V.A. Boyett, J.T. Hardke, and C.E. Wilson Jr....... 70

Development of Aromatic Rice Varieties
D.K.A. Wisdom, K.A.K. Moldenhauer, C.E. Wilson Jr., X. Sha, J.M. Bulloch, B.A. Beaty, M.M. Blocker, and V.A. Boyett.................................. 79

PEST MANAGEMENT: DISEASES

Seed Management to Control Bacterial Panicle Blight of Rice
S.B. Belmar, C.D. Kelsey, T.A. Gebremariam, and Y.A. Wamishe 82

Disease Component Analysis of the Infection of Four Rice Cultivars, Jupiter, Katy, Neptune, and Roy J, by an Albinotic Strain of the False Smut Pathogen Recently Found in Arkansas
D.O. TeBeest and A.C. Jecmen 95

Characterization of Rice Germplasm for Genetic Resistance to Bacterial Panicle Blight Disease and Development of Techniques for Monitoring the Bacterial Pathogen
Y.A. Wamishe, Y. Jia, T. Gebremariam, C. Kelsey, S. Belmar, and T. Mulaw ... 109

Studies on Cultural Management Options for Rice Bacterial Panicle Blight Disease
Y.A. Wamishe, T. Gebremariam, S. Belmar, C. Kelsey, and T. Mulaw 118

PEST MANAGEMENT: INSECTS

Stored-Product Insects Associated with On-Farm Storage Sites
T. McKay, M. Bowombe Toko, B. Hale, R. Hampton, and L. Starkus............... 127

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas 2011-2013
W.A. Plummer, G.M. Lorenz, N.M. Taillon, H.M. Chaney, B.C. Thrash, D.L. Clarkson, M.E. Everett, and L.R. Orellana Jimenez................................ 132

Insecticide Seed Treatments in Rice: Is There Value to the Grower?
N.M. Taillon, G.M. Lorenz, J. Black, W.A. Plummer, and H.M. Chaney.......... 137

PEST MANAGEMENT: WEEDS

Weed Control and Crop Response to Sharpen Tank Mixes in Rice
R.C. Doherty, L.T. Barber, L.M. Collie, and A.W. Ross 145

Residual Activity of Quizalofop on Grass Weeds and Crops Compared to Other Graminicides
Z.D. Lancaster, J.K. Norsworthy, M.G. Palhano, S.M. Martin, R.R. Hale, and R.C. Scott.. 150

Comparison of Insecticide Seed Treatments for Lessening Rice Injury Following Herbicide Drift
S.M. Martin, J.K. Norsworthy, R.C. Scott, G.M. Lorenz III, J. Hardke, and Z.D. Lancaster 157

Use of Cruiser Maxx® Rice Seed Treatment to Improve Tolerance of Conventional Rice to Newpath (Imazethapyr) and Roundup (Glyphosate) at Reduced Rates Over 2 Years
R.C. Scott, G. Lorenz, J.T. Hardke, J.K. Norsworthy, and B.M. Davis 165

First Report of Acetolactate Synthase-Resistant Yellow Nutsedge in Arkansas Rice: Confirmation and Control
P. Tehranchian, J.K. Norsworthy, M.V. Bagavathiannan, D.S. Riar, M.T. Bararpour, and R.C. Scott 172

RICE CULTURE

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2014
E. Castaneda-Gonzalez, D.L. Frizzell, J.T. Hardke, Y.A. Wamishe, and R.J. Norman 179

Validation of the Nitrogen Soil Test for Rice (N-STaR) on Clay Soils in Arkansas
J.T. Davidson, T.L. Roberts, C.E. Greub, A.M. Fulford, N.A. Slaton, J. Hardke, J. Shafer, S. Williamson, and C. Scott 195

Ammonia Volatilization and Rice Grain Yield as Affected by Simulated Rainfall Amount and Nitrogen Fertilizer Amendment
R.J. Dempsey, N.A. Slaton, T.L. Roberts, R.J. Norman, R.E. DeLong, M.S. Fryer, and M.R. Parvej 202

Rice Grain Yield as Affected by Simulated Rainfall Timing and Nitrogen Fertilizer Amendment
R.J. Dempsey, N.A. Slaton, T.L. Roberts, R.J. Norman, R.E. DeLong, M.S. Fryer, and M.R. Parvej 208

Planting Date Studies and Development of Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars, 2014
D.L. Frizzell, J.T. Hardke, E. Castaneda-Gonzalez, R.J. Norman, K.A.K. Moldenhauer, and X. Sha 214

Influence of Nitrogen Rate and Seeding Rate on Grain Yield of
Roy J Rice Grown at Two Locations in Arkansas—First Year Results
*D.L. Frizzell, J.T. Hardke, E. Castaneda-Gonzalez,
R.J. Norman, and M.W. Duren* 222

Validation of Soil-Test-Based Fertilizer Recommendations for Rice
*M. Fryer, N.A. Slaton, T.L. Roberts, J. Hardke. R.E. DeLong,
R. Dempsey, M.R. Parvej, J. Hedge, and S. Hayes* 229

Effects of Water-Saving Rice Cultivation Methods on Yield,
Water Use, and Water-Use Efficiency
*J.P. Gaspar, C.G. Henry, M.M. Anders, M. Duren,
D. Hendrix, and A.P. Horton* 236

Arkansas Rice Performance Trials, 2012-2014
*J.T. Hardke, D.L. Frizzell, E. Castaneda, K.A.K. Moldenhauer,
X. Sha, G. Berger, Y. Wamishe, R.J. Norman, M.M. Blocker, J.A. Bulloch,
T. Beaty, R. Mazzanti, R. Baker, W. Kirkpatrick, and M. Duren* 247

Grain Yield Response of Five New Rice Varieties to Nitrogen Fertilization
*R.J. Norman, T.L Roberts, J.T. Hardke, N.A. Slaton, K.A.K. Moldenhauer,
D.L. Frizzell, M.W. Duren, E. Castaneda-Gonzalez, and A.M. Fulford* 256

Rice Grain Yield as Influenced by Various Water Management Practices
*T.L. Roberts, J.T. Hardke, N.A. Slaton, C.E. Greub,
J.T. Davidson, A.M. Fulford, S.M. Williamson, C.L. Scott,
D.L. Frizzell, and E. Castaneda-Gonzalez* 272

The Effect of Delaying Preflood-Nitrogen Fertilization on
Grain Yield of Flood-Irrigated Rice
*N.A. Slaton, T.L. Roberts, J. Hardke, R.J. Norman,
R.E. DeLong, R. Dempsey, M. Fryer, R. Parvej, and J. Hedge* 277

Rice and Soybean Response to Short- and Long-Term Phosphorus
and Potassium Fertilization Rate
*N.A. Slaton, T.L. Roberts, R.J. Norman, J.T. Hardke,
R.E. DeLong, J.B. Shafer, C.G. Massey, and S.D. Clark* 281

Growing-Season Methane Fluxes and Emissions from a
Silt Loam Soil as Influenced by Rice Cultivar
*A.D. Smartt, C.W. Rogers, K.R. Brye, R.J. Norman, W.J. Smartt,
J.T. Hardke, D.L. Frizzell, and E. Castaneda-Gonzalez* 289

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2014
S.M. Williamson, T.L. Roberts, C.L. Scott, N.A. Slaton, J. Shafer and C.E. Greub *298*

RICE QUALITY AND PROCESSING

Microbial Prevalence on Freshly Harvested Long-Grain Hybrid, Long-Grain Pure-Line, and Medium-Grain Rice
G.G. Atungulu, H. Zhong, S. Thote, A. Okeyo, A. Couch, S. Sadaka, and T. Siebenmorgen *306*

A Comparison of Methods Used to Quantify Chalkiness of Head Rice
B.C. Grigg and T.J. Siebenmorgen *314*

Functional Properties of Commingled Rice-Cultivar Lots
K.N. Haydon, N.N. Basutkar, T.J. Siebenmorgen, and Y.-J. Wang *321*

Physical and Functional Characteristics of Broken Rice Kernels Created by Rapid Moisture Adsorption
S. Mukhopadhyay and T.J. Siebenmorgen *330*

Effects of Chalkiness Level on Sensory Aspects of Raw and Cooked Rice
H.-S. Seo, C. Duez, S. Cho, Y.-J. Wang, and T.J. Siebenmorgen *340*

ECONOMICS

Genetically Modified Rice Commercialization and Its Impact on the Global Rice Economy
A. Durand-Morat, E.C. Chavez, and E.J. Wailes *346*

Rice Enterprise Budgets and Production Economic Analysis
W.A. Flanders *361*

An Overview of Federal Crop Insurance Corporation (FCIC) Programs for Rice Producers in Arkansas, 2011 to 2014
R.U. Mane and K.B. Watkins *365*

World and U.S. Rice Outlook: Deterministic and Stochastic Baseline Projections, 2014-2024
E.J. Wailes and E.C. Chavez *374*

Trends in Arkansas Rice Production, 2014

J.T. Hardke

ABSTRACT

Arkansas is the leading rice-producing state in the United States. The state represents 50.7% of total U.S. rice production and 50.6% of the total acres planted to rice in 2014. Rice cultural practices vary across the state and across the U.S. However, these practices are also dynamic and continue to evolve in response to changing political, environmental, and economic times. This survey was initiated in 2002 to monitor and record changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas System Division of Agriculture's Rice DD50 program was included to summarize variety acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

INTRODUCTION

Arkansas is the leading rice-producing state in the United States in terms of acreage planted, acreage harvested, and total production. Each year, rice planting typically ranges from late March into early June with harvest occurring from late August to early November. Rice production occurs across a wide range of environments in the state. The diverse conditions under which rice is produced leads to variation in the adoption and utilization of different crop management practices. To monitor and better understand changes in rice production practices, including adoption of new practices, a survey was initiated in 2002 to record annual production practices. Information obtained through this survey helps to illustrate the long-term evolution of cultural practices for rice production in Arkansas. It also serves to provide information to researchers and extension personnel about the ever-changing challenges facing Arkansas rice producers.

PROCEDURES

A survey has been conducted annually since 2002 by polling county agriculture extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information was obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture's Rice DD50 program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely produced cultivars. RiceTec CLXL745 was the most widely planted cultivar in 2014 at 22.0% of the acreage, followed by Jupiter (13.0%), CL151 (12.6%), Roy J (12.6%), RiceTec XL753 (11.8%), CL111 (5.0%), Mermentau (4.9%), RiceTec CLXL729 (4.2%), CL152 (3.3%), and Wells (2.9%). Additional cultivars of importance in 2014, though not shown in Table 1, were Francis, Taggart, Cheniere, and RiceTec XL723.

Arkansas producers planted 1,486,000 acres of rice in 2014 which accounted for 50.6% of the total U.S. rice crop in 2014 (Table 2). The state-average yield of 7,560 lb/acre (168 bu/acre) tied the state record yield set in 2013. The average yields in Arkansas represented the second highest average in the U.S. behind California. The total rice produced in Arkansas during 2014 was 111.96 million hundredweight (cwt). This represents 50.7% of the 221.0 million cwt produced in the U.S. during 2014. Over the past 3 years, Arkansas has produced 47.3% of all rice produced in the U.S. The six largest rice-producing counties in Arkansas during 2014 included Poinsett, Jackson, Lawrence, Arkansas, Lonoke, and Cross, representing 40.2% of the state's total rice acreage (Table 1).

Planting in 2014 started behind the 5-year state average due to cold, wet conditions throughout March, April, and early May (Fig. 1). Planting progress was only 47% by 27 April in 2014 compared to an average of 61% planting progress by this date in previous years. Planting was almost fully complete by 1 June. While planting progress was notably delayed by early-season weather, mild and favorable weather conditions led to harvest progressing at a similar rate to the planting progress, and similar to the 5-year average (Fig. 2). About 44% of the crop was harvested by 21 September compared with 54% harvest progress on the same date in previous years. Harvest progress was nearly complete (98%) by 2 November.

Approximately 60% of the rice produced in Arkansas was planted using conventional tillage methods in 2014 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres are planted using stale seedbed (32.6%) or no-till (7.7%) systems. True no-till rice production is not common but is done in a few select regions of the state.

The majority (55.8%) of rice is still produced on silt loam soils (Table 3). Rice production on clay or clay loam soils (19.6% and 21.1%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil texture present unique challenges in rice production such as tillage practices, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation, accounting for 72.2% of the rice acreage (Table 3). Approximately 22% of the acreage in 2014 was planted following rice, with the remainder made up of rotation with other crops including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only 4% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting all available water and re-using. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 77.4% of the rice acreage in Arkansas with the remaining 22.6% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990s, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet irrigation which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2014, rice farmers utilize this practice on 39.6% of the rice acreage (Table 3). About 60% of rice is still irrigated with conventional levee and gate systems. A small percentage of rice acreage is produced in more upland conditions utilizing furrow or overhead irrigation systems. Intermittent flooding is another means of irrigation receiving interest recently as a means to reduce pumping costs and water use; but the practice accounts for little acreage at this time.

Stubble management is important for preparing fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding (Table 3). In 2014, 28.0% of the acreage was burned, 36.3% was tilled, 37.0% was rolled, and 19.9% was winter flooded. Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 57.7% of rice acres in 2014 (Table 3). This number was higher than in recent years likely due to moderate temperatures, frequent rainfall, and cloudy weather late in the growing season for the northern half of the state which promoted development of disease—namely sheath blight and blast. Nearly 36% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were notably lower than in 2013. Insecticide seed treatments were used on 70.8%

of rice acreage as producers continue to adopt this technology more widely each year due to its benefits for both insect control and improved plant growth and vigor.

Clearfield rice continues to play a significant role in rice production in Arkansas. This technology (all cultivars combined) accounted for 49% of the total rice acreage in 2014 (Fig. 3). This represents a 7% decrease in Clearfield rice acreage compared to 2013 and the third consecutive year of acreage decline. Proper stewardship of this technology will be the key to its continued success on the majority of rice acres. In areas where stewardship has been poor, imadazolinone-resistant barnyardgrass has been discovered. Evidence of these resistant populations may have served to reduce the number of Clearfield acres by emphasizing the negative effects of improper technology management. In addition, multiple years of this technology and crop rotation have likely cleaned up many red-rice fields to the point where they can be safely returned to conventional rice production.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state average yields in Arkansas have increased approximately 2,115 lb/acre (about 47 bu/acre) or 2.35 bu/acre/year. This increase can be attributed to the development and adoption of more productive cultivars and improved management practices, including better herbicides, fungicides, and insecticides; improved water management through precision-leveling and multiple-inlet irrigation; improved fertilizer efficiency; and increased understanding of other practices such as seeding dates and tillage. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

ACKNOWLEDGMENTS

The author would like to extend thanks to the rice farmers of Arkansas who provide support through the rice check-off program; all of the county agents who participated in this survey; and the members of the Rice Agronomy crew: Donna Frizzell, Eduardo Castaneda-Gonzalez, Chuck Pipkins, Ralph Mazzanti, and Ron Baker.

LITERATURE CITED

USDA-NASS. 2015. United States Department of Agriculture National Agricultural Statistics Service. Accessed: 16 Feb. 2015. http://usda.mannlib.cornell.edu/usda/current/CropProdSu/CropProdSu-01-12-2015_revision.pdf

This page left blank intentionally to facilitate the following tables.

Table 1. 2014 Arkansas

County	Harvested acreage[a]		Medium-grain		Long-grain-
	2013	2014	Jupiter	Others[b]	CL111
Arkansas	71,885	91,155	6,444	3,253	1,345
Ashley	4,533	11,182	855	0	549
Chicot	25,107	34,839	536	0	2,615
Clay	64,740	81,506	8,124	549	3,818
Craighead	57,987	71,509	12,652	466	4,758
Crittenden	21,568	51,036	8,395	923	0
Cross	65,315	88,036	15,776	1,425	10,070
Desha	9,605	25,266	6,034	0	0
Drew	7,116	11,312	314	0	0
Faulkner	1,815	2,582	0	0	0
Greene	62,804	78,405	6,714	0	0
Independence	7,764	12,747	2,148	0	3,099
Jackson	68,299	104,194	30,730	1,883	3,000
Jefferson	55,438	72,463	1,892	0	0
Lafayette	3,164	4,434	0	0	443
Lawrence	83,775	99,922	10,216	5,309	4,466
Lee	16,540	29,920	2,006	0	900
Lincoln	12,104	21,516	393	0	0
Lonoke	68,474	89,732	4,539	0	2,642
Mississippi	27,261	53,540	1,362	0	9,196
Monroe	37,199	59,492	4,934	2,460	1,212
Phillips	18,177	32,643	806	0	0
Poinsett	86,445	121,569	38,865	1,625	6,474
Pope	1,531	2,205	0	0	0
Prairie	54,202	63,640	6,817	1,702	4,558
Pulaski	3,371	4,168	128	0	0
Randolph	29,145	35,657	8,952	0	2,523
St. Francis	26,454	38,443	5,688	396	184
WHITE	9,885	13,192	1,890	0	0
WOODRUFF	47,389	61,925	4,707	0	11,236
Others[c]	6,100	6,989	0	0	323
Unaccounted[d]	14,808	4,781			
2014 Total		1,480,000	191,915	19,990	73,412
2014 Percent		100	12.97	1.35	4.96
2013 Total	1,070,000		106,396	8,207	63,749
2013 Percent	100		9.94	0.77	5.96

[a] Harvested acreage. Source: USDA-NASS, 2015.

[b] Other varieties: AB647, Antonio, CL142-AR, CL261, Caffey, Cheniere, Cocodrie, Della-2, Francis, Jazzman, Jazzman-2, LaKast, RiceTec CLXL746, RiceTec CLXP4534, RiceTec XL723, RiceTec XP4523, Rosemont, and Taggart.

[c] Other counties: Clark, Conway, Franklin, Hot Spring, Little River, Miller, Perry, and Yell.

[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and preliminary estimates obtained from each county FSA.

harvested rice acreage summary.

		Long-grain						
CL151	CL152	Mermentau	CLXL729	CLXL745	XL753	Roy J	Wells	Others[b]
2,422	2,691	2,440	946	28,255	22,470	9,685	891	10,313
549	549	0	2,197	2,746	2,636	549	0	549
2,092	2,092	1,098	3,660	12,550	6,449	2,440	0	1,307
33,405	2,863	2,386	0	17,857	10,499	1,145	145	716
11,894	4,418	4,214	0	5,478	5,383	8,156	8,156	5,933
197	492	962	2,403	13,800	11,308	6,637	0	5,919
11,682	3,222	3,222	290	11,682	11,279	17,418	223	1,748
5,851	1,984	1,945	0	6,849	2,097	506	0	0
3,704	2,580	0	0	3,158	1,556	0	0	0
0	0	594	0	671	645	361	0	310
29,268	1,802	1,771	0	28,028	5,391	770	0	4,660
3,595	0	0	0	3,409	0	0	496	0
18,500	3,390	6,035	5,940	11,839	8,030	10,000	0	4,848
0	0	1,086	0	55,589	2,533	10,133	0	1,230
554	554	0	0	1,330	443	665	0	443
15,185	5,359	8,486	357	10,719	4,707	24,563	0	10,555
0	0	840	3,752	3,002	4,502	13,897	0	1,021
0	0	3,391	0	4,675	10,922	2,135	0	0
2,202	2,642	3,402	10,675	42,276	9,688	3,814	7,046	806
2,627	0	5,255	0	8,828	5,255	2,627	15,764	2,627
727	0	5,206	3,636	8,787	3,030	17,271	1,480	10,751
0	3,265	6,531	0	3,102	9,796	6,531	1,306	1,306
26,933	3,885	4,273	3,885	6,474	5,827	11,434	5,179	6,716
902	110	0	0	1,193	0	0	0	0
1,042	3,907	3,516	4,083	20,186	7,163	3,907	0	6,759
209	209	0	626	2,371	417	209	0	0
3,604	360	0	5,587	1,405	6,018	0	0	7,208
2,472	184	2,472	0	1,129	5,902	16,600	885	2,531
638	64	926	1,686	2,105	5,448	0	0	435
4,994	1,873	1,873	12,485	4,994	4,994	13,146	0	1,623
1,272	152	503	238	1,530	236	1,421	586	729
								4,781
186,518	48,648	72,426	62,445	326,016	174,626	186,022	42,156	95,825
12.60	3.29	4.89	4.22	22.03	11.80	12.57	2.85	6.47
103,897	82,903	10,500	79,479	238,356	66,474	147,961	33,601	128,476
9.71	7.75	0.98	7.43	22.28	6.21	13.83	3.14	12.01

Table 2. Acreage, grain yield, and production of rice in the United States from 2012 to 2014.[a]

	Area planted			Area harvested			Yield			Production		
State	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
	(1,000 acres)						(lb/acre)			(1,000 cwt[b])		
Arkansas	1,291	1,076	1,486	1,285	1,070	1,480	7,480	7,560	7,560	96,109	80,888	111,957
California	562	567	434	557	562	431	8,150	8,480	8,580	45,413	47,641	36,993
Lousiana	402	418	462	397	413	458	6,430	7,300	7,130	25,540	30,135	32,658
Mississippi	130	125	191	129	124	190	7,200	7,400	7,420	9,288	9,176	14,096
Missouri	180	159	216	177	156	213	6,990	7,030	6,830	12,372	10,968	14,540
Texas	135	145	150	134	144	147	8,370	7,740	7,340	11,217	11,145	10,791
US	2,700	2,490	2,939	2,679	2,469	2,919	7,463	7,694	7,572	199,939	189,953	221,035

[a] Source: USDA-NASS, 2015.
[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production.[a]

	2012		2013		2014	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,785,000	100.00	----	----	1,235,510	0.00
Soil texture						
Clay	267,547	20.8	209,251	19.6	290,508	19.6
Clay loam	282,736	22.0	252,702	23.6	311,721	21.1
Silt loam	677,951	52.8	547,386	51.2	825,486	55.8
Sandy loam	47,819	3.7	45,733	4.3	41,474	2.8
Sand	8,945	0.7	14,928	1.4	10,811	0.7
Tillage practices						
Conventional	716,782	55.8	654,647	61.2	883,586	59.7
Stale seedbed	445,484	34.7	329,807	30.8	482,323	32.6
No-till	122,734	9.6	85,546	8.0	114,090	7.7
Crop rotations						
Soybean	916,297	71.3	759,792	71.0	1,069,283	72.2
Rice	311,366	24.2	225,690	21.1	317,662	21.5
Cotton	3,199	0.2	5,586	0.5	4,030	0.3
Corn	35,035	2.7	45,006	4.2	41,093	2.8
Grain sorghum	6,519	0.5	6,810	0.6	11,532	0.8
Wheat	1,798	0.1	13,107	1.2	7,222	0.5
Fallow	10,784	0.8	13,705	1.3	29,178	2.0
Other	0	0.0	305	0.0	0	0.0
Seeding methods						
Drill seeded	1,025,022	79.8	881,172	82.4	1,250,157	84.5
Broadcast seeded	259,988	20.2	183,112	17.1	229,843	15.5
Water seeded	65,984	5.1	32,570	3.0	61,221	4.1
Irrigation water sources						
Groundwater	987,160	76.8	848,435	79.3	1,145,847	77.4
Stream, rivers, etc.	165,619	12.9	109,822	10.3	178,807	12.1
Reservoirs	132,219	10.3	111,743	10.4	155,345	10.5
Irrigation methods						
Flood, levees	785,104	61.1	698,139	65.2	885,796	59.9
Flood, multiple inlet	495,357	38.5	368,092	34.4	585,658	39.6
Furrow	4,323	0.3	3,769	0.4	6,203	0.4
Sprinkler	214	0.0	0	0.0	458	0.0
Other	0	0.0	0	0.0	1,885	0.1

continued

Table 3. Continued.

	2012		2013		2014	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Stubble management						
Burned	327,698	25.5	303,204	28.3	414,650	28.0
Tilled	494,574	38.5	430,519	40.2	537,686	36.3
Rolled	289,202	22.5	316,705	29.6	548,333	37.0
Winter Flooded	231,624	18.0	203,971	19.1	294,729	19.9
Land management						
Contour levees	432,724	33.7	345,944	32.3	402,239	27.2
Precision-level	719,358	56.0	603,039	56.4	896,041	60.5
Zero-grade	132,918	10.3	121,016	11.3	181,720	12.3
Precision agriculture						
Yield monitors	748,705	58.3	553,505	51.7	877,850	59.3
Grid sampling	311,706	24.3	240,490	22.5	437,759	29.6
Variable-rate	287,254	22.4	202,822	19.0	367,045	24.8
Pest management						
Insecticide seed treatment	746,456	58.1	653,049	61.0	1,047,204	70.8
Fungicide (foliar application)	593,723	46.2	578,201	54.0	853,570	57.7
Insecticide (foliar application)	373,251	29.0	457,649	42.8	526,939	35.6

[a] Data generated from surveys of county agriculture extension agents.

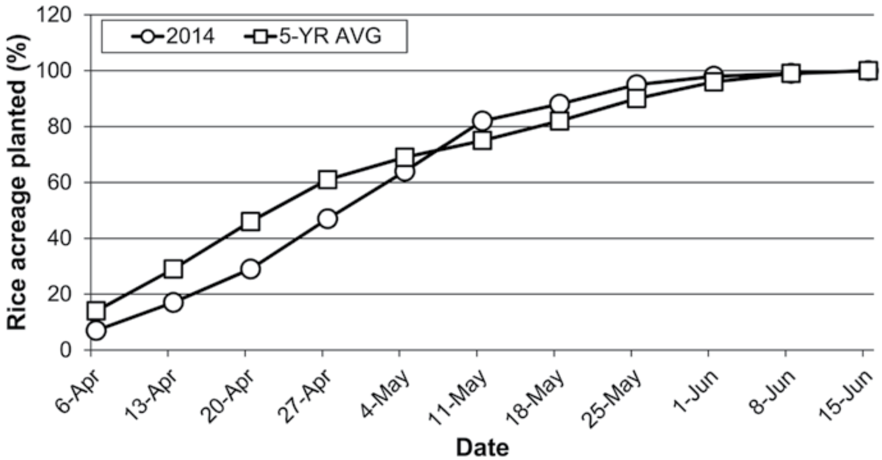


Fig. 1. Arkansas rice planting progress during 2014 compared to the five-year state average (USDA-NASS, 2015).

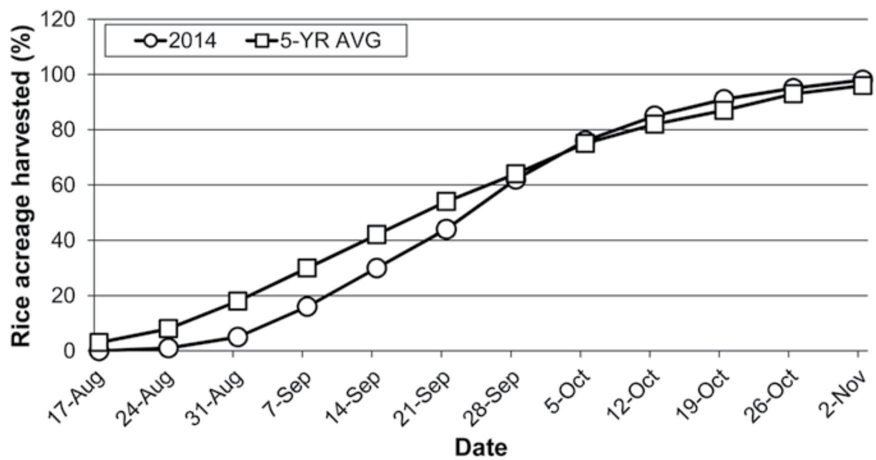


Fig. 2. Arkansas rice harvest progress during 2014 compared to the five-year state average (USDA-NASS, 2015).

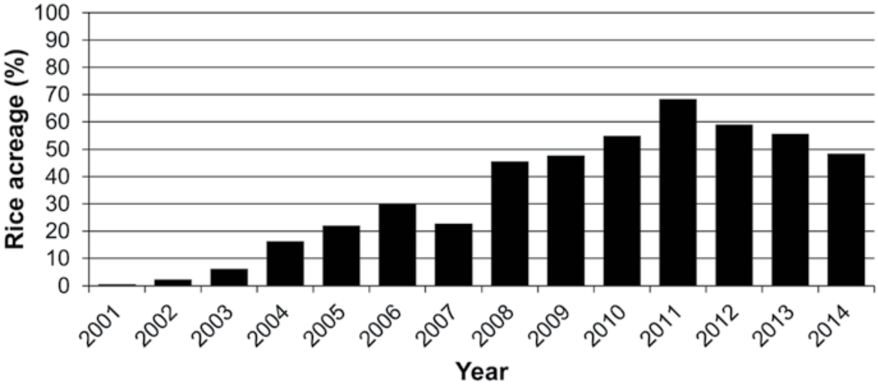


Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2014.

2014 Rice Research Verification Program

R.S. Mazzanti, R. Baker, J.T. Hardke, K.B Watkins, and R. Mane

ABSTRACT

The 2014 Rice Research Verification Program (RRVP) was conducted on 15 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Chicot (2 fields), Clay, Desha, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Monroe, Prairie, St. Francis, White, and Yell Counties for a total of 766 acres. Grain yield in the 2014 RRVP averaged 189 bu/acre ranging from 150 to 252 bu/acre. The 2014 RRVP average yield was 21 bu/acre greater than the estimated Arkansas state average of 168 bu/acre. The highest-yielding field was in Chicot County with a grain yield of 252 bu/acre. The lowest-yielding field was in Monroe County and produced 150 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 59/70 (i.e., head rice/total white rice).

INTRODUCTION

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service recommendations in fields with less than optimum yields or returns.

The goals of the RRVP are to: 1) educate producers on the benefits of utilizing Cooperative Extension Service recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, 5) incorporate data from RRVP into Extension educational programs at the county and state level. Since 1983, the RRVP has been conducted on 416 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged 20 bu/acre better than the state average yield. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

PROCEDURES

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement Cooperative Extension Service recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents were made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee, consisting of Extension specialists and university researchers with rice responsibility, assists in decision-making, development of recommendations, and program direction. Field inspections by committee members were utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2014 included Arkansas, Chicot (2 fields), Clay, Desha, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Monroe, Prairie, St. Francis, White, and Yell Counties. The 15 rice fields totaled 766 acres enrolled in the program. Seven different cultivars were seeded (i.e., CL151, RiceTec CL XL745, Roy J, RiceTec XL753, Mermentau, LaKast, and Cheniere) and Cooperative Extension Service recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy is utilized based on Cooperative Extension Service recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

RESULTS AND DISCUSSION

Yield

The average RRVP yield was 189 bu/acre with a range of 150 to 252 bu/acre (Table 1). The RRVP average yield was 21 bu/acre more than the estimated state yield of 168 bu/acre. This difference has been observed many times since the program began and can be attributed in part to intensive management practices and utilization of Cooperative Extension Service recommendations. The Chicot County field, seeded with Rice Tec XL753, was the highest yielding RRVP field at 252 bu/acre. Ten of the 15 fields enrolled in the program exceeded 180 bu/acre. Monroe County had the lowest yielding field with Roy J producing 150 bu/acre.

Milling data was recorded on all of the RRVP fields. The average milling yield for the fifteen fields was 59/70 (head rice/total white rice) with the highest milling yield of 67/71 with Mermentau in St. Francis County (Table 1). The lowest milling yield was 56/68 with Mermentau in Yell County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Arkansas County on 4 April and ended with Jefferson County planted on 25 May (Table 1). Seven of the verification fields were planted in April and 8 in May. An average of 79 lb seed/acre was planted for pure-line varieties and 24 lb seed/acre for hybrids. Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 12 days was required for emergence. Stand density averaged ~20 plants/square foot (ft^2) for pure-line varieties and 7 plants/ft^2 for hybrids. The seeding rates in some fields were higher than average due to planting method, soil texture, and late planting dates. Broadcast seeding and clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized on 12 of 15 RRVP fields. Only fields enrolled late in the RRVP did not use N-STaR (Table 2). Nitrogen (N) recommendations for fields not using N-STaR were based on a combination of factors including soil texture, previous crop, and cultivar requirements. Nitrogen rates can appear high in some fields with a clay soil texture and rice as the previous crop. These factors increase the N requirements compared to a silt loam soil where soybeans were the previous crop.

Ammonium sulfate (21-0-0-24) was applied in some fields at the 2- to 3-leaf stage as a management tool to increase plant growth and shorten the time required to get the rice to flood stage or to correct sulfur deficiencies (Table 2). Ammonium sulfate was applied at a rate of 75 to 100 lb/acre in Arkansas, Chicot #2, Clay, Desha, and Lincoln Counties.

Phosphorus, potassium, and zinc were applied based on soil-test results (Table 2). Phosphorus and/or potassium and zinc were applied pre-plant in most of the fields. Phosphorus was applied to Arkansas, Chicot #1, Clay, Jefferson, Lawrence, Lee, Lonoke, Monroe, Prairie, St. Francis, and White County fields. Zinc was applied as a seed treatment in fields with hybrid rice cultivars at a rate of 0.5 lb Zn/60 lb seed. The average cost of fertilizer across all fields was $98.48 (Table 3).

Weed Control

Command or Obey (i.e., Command + Facet) were utilized in 12 of the 15 fields for early-season grass control (Table 4). Facet or Obey were applied in 9 of the 15 fields either pre-emergence or early post-emergence. Three fields (Arkansas, Clay, and Lonoke Counties) were seeded in Clearfield cultivars and Newpath and Clearpath were applied for control of red rice and other weeds. All of the fields required a post-emergence herbicide application for grass weed control.

Disease Control

Thirteen fields had a seed treatment containing a fungicide (Table 5). The foliar fungicides Quilt Xcel, Tilt, or Stratego were applied to 5 of the 15 fields in 2014 for control of sheath blight and/or suppression of false smut and kernel smut. One field (Clay County) received an application of the fungicide Stratego for control of rice blast. Fungicide rates were determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history.

Insect Control

Two fields (Arkansas and Chicot #1 Counties) were treated with a foliar insecticide application for rice stink bugs in 2014 (Table 5). Eight fields (Clay, Jefferson, Lawrence, Lee, Lonoke, St. Francis, White, and Yell Counties) received an insecticide seed treatment in the form of CruiserMaxx Rice or NipsIt INSIDE.

Irrigation

Well water was used to irrigate 9 of the 15 fields in the 2014 RRVP while 6 fields were irrigated with surface water. Two fields (Lonoke and Prairie Counties) were zero-grade. Two fields (Clay and Lawrence Counties) used multiple-inlet (MI) irrigation either by utilizing irrigation tubing or by having multiple risers or water sources. Flow meters were used in 11 of the fields to record water usage throughout the growing season. In fields where flow meters were not utilized, the average across all irrigation methods of 30 acre-inches was used (Table 6).

The difference in water used was due in part to rainfall amounts which ranged from 9.9 inches to 22.4 inches. Typically, a 25% reduction in water use is measured when using MI irrigation.

Economic Analysis

This section provides information on production costs and returns for the 2014 RRVP. Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 15 fields were utilized to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all operating inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2014 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs and actual cash outlays could differ as producers provide unpaid labor for equipment maintenance.

Fixed costs of machinery are determined by a capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production. Machinery costs are estimated by applying engineering formulas to representative prices of new equipment. This measure differs from typical depreciation methods as well as actual annual cash expenses for machinery.

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 7. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs ranged from $417.67/acre for White County to $682.64 and $682.03/acre for Lincoln and Arkansas Counties, respectively, while operating costs per bushel range from $2.38/bu for Chicot County #2 to $3.81/bu for Monroe County. Total costs per acre (operating plus fixed) ranged from $538.06/acre for White County to $820.35/acre for Lawrence County, and total costs per bushel ranged from $2.66/bu for Chicot County #2 to $4.64/bu for Monroe County. Returns above operating costs ranged from $241.87/acre for Monroe County to $814.15/acre for Chicot County #2 with an average return above operating costs for the 15 fields of $490.42/acre. Returns above total costs ranged from $116.35/acre for Monroe County to $743.96/acre for Chicot County #2 with an average return above total costs for the 15 fields of $392.05/acre.

A summary of yield, rice price, revenues, and expenses by type for each RRVP field is presented in Table 3. The average rice yield for the 2014 RRVP was 189 bu/acre but ranged from 150 bu/acre for Monroe County to 252 bu/acre for Chicot County #2. The Arkansas average long-grain cash price for the 2014 RRVP was estimated from 1 August through 31 October daily price quotes to be $5.40/bu. A premium or discount was given to each field based on the actual milling yield observed for each field and standard milling yields of 55/70 for long-grain rice. If milling yield was higher than the standard, a premium was made while a discount was given for milling less than the standard. Estimated long-grain prices adjusted for milling yield varied from $5.30/bu in White and Yell Counties to $5.82/bu in Lincoln County.

The average operating expense for the 15 RRVP fields was $554.11/acre (Table 3). Post-harvest expenses accounted for the largest share of operating expenses on average (19.9%) followed by fertilizers and nutrients (17.8%), seed (15.4%), and chemicals (13.8%). Although seed cost accounted for 15.4% of operating expenses across the 15 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($140.28/acre; 20.6% of operating expenses), a non-Clearfield hybrid was used ($152.33/acre; 26.1% of operating expenses), a Clearfield non-hybrid (pure-line) variety was used ($79.33/acre; 13.5% of operating expenses) or a non-Clearfield non-hybrid (pure-line) variety was used ($46.81/acre; 9.1% of operating expenses).

Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. The table also lists the specific rice cultivars grown on each RRVP field.

DISCUSSION

Field Summaries

The 78-acre Arkansas County field was located southeast of Stuttgart on a Dewitt silt loam soil. The previous crop was soybean. Conventional tillage practices were used for field preparation and a pre-plant fertilizer, based on soil-test recommendations, was applied at a rate of 24-50-60-90-10-21 (lb/acre N-P_2O_5-K_2O-Zn-S). RiceTec CL XL745 was drill-seeded on 4 April at 19 lb/acre. CruiserMaxx Rice insecticide seed treatment was used in addition to the company's standard seed treatment. The rice emerged on 14 April with a stand density of 6 plants/ft^2. Ammonium sulfate was used as a starter fertilizer at a rate of 100 lb/acre applied 2 May. Due to extended high wind issues, the post-emergence herbicide application was delayed. Clearpath and Prowl were applied 2 May as a pre-emergence herbicide and provided adequate weed control. Newpath and Permit Plus were applied 23 May and provided sufficient control of barnyardgrass and dayflower. Using the N-STaR recommendation, pre-flood urea + NBPT was applied at a rate of 225 lb/acre on 24 May. Multiple-inlet irrigation was utilized for the field ensuring a more efficient permanent flood establishment. On 12 July, urea was applied at late-boot stage at 70 lb/acre. The field was clean throughout the year and a deep flood was maintained. Irrigation amount was 21 acre-inches with rainfall amount totaling 14.5 inches. No fungicides were needed for disease control, but rice stink bugs reached threshold levels and Karate insecticide was applied on 25 July. The field was harvested on 29 August and yielded 222 bu/acre. The average harvest moisture was 19% and the milling yield was 60/71. This was the second-highest yield this year in the RRVP.

The 74-acre, precision-graded Chicot County #1 field was located northwest of Eudora on a Perry clay soil. The field was fallow the previous year due to land forming. On 23 April, RiceTec XL753, treated with CruiserMaxx Rice insecticide in addition to the company's standard seed treatment, was drilled at 24 lb/acre. Diammonium phosphate fertilizer (18-46-0) was applied according to soil-test recommendations. Roundup, Command, and League were applied on 24 April for burndown and as pre-emergence herbicides. Continual rainfall on a weekly basis provided residual weed control for 28 days. Field emergence was recorded on 3 May with a stand density of 6 plants/ft^2.

On 22 May, Facet, Permit, and League were applied as post-emergence herbicides. Multiple-inlet irrigation was utilized and an adequate flood was maintained throughout the year. Based on N-STaR recommendations, N was applied as urea pre-flood at 270 lb/acre on 23 May. Late boot N fertilizer was applied on 7 July at 70 lb/acre as urea. Rice stink bugs reached treatment levels and Mustang Max insecticide was applied on 20 July. Rainfall amounts were 21 inches for the season. Irrigation amount was 11 acre-inches. The field was harvested 28 August with a yield of 188 bu/acre and milling yield of 58/70. The harvest moisture averaged 21%. The grower was well pleased with the yield considering the field was land formed in late 2013.

The zero-grade, 60-acre Chicot County #2 field was located south of Lake Village on Perry clay soil. The previous crop was soybean. Conventional tillage practices were utilized in the spring. RiceTec XL753 was drill-seeded at 26 lb/acre on 24 April. The seed was treated with CruiserMaxx Rice insecticide and Rice Tec's standard seed treatment. Roundup, League, and Command herbicides were applied on 22 April as burndown and as a pre-emergence. Emergence was observed on 1 May with 7 plants/ft^2. Ammonium sulfate was applied on 18 May as a starter fertilizer at 100 lb/acre. Continual rainfall gave lasting herbicide residual control for over 26 days. On 18 May, Facet and League herbicides were applied. The total herbicide cost for the field was $54/acre which is $30 below the RRVP average. A single preflood N application was made using urea with NBPT on 26 May at 354 lb/acre. The field was harvested on 4 September with an all-time, 31-year RRVP record of 252 bu/acre. The milling yield was 59/72 and the average moisture was 19%. The rainfall amount for the growing season was 20.5 inches and irrigation averaged 10 acre-inches .

The precision-graded Clay County field was located southwest of Corning on a Jackport silty clay loam soil. The field was 76 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the spring and a pre-plant fertilizer based on soil test analysis was applied at a rate of 10-40-60-0-12 (lb/acre N-P_2O_5-K_2O-Zn-S). On 2 April, CL151 with CruiserMaxx Rice insecticide seed treatment was drill-seeded at a rate of 70 lb/acre. Rice emergence was observed on 14 April and consisted of 20 plants/ft^2. Command herbicide at a 12.8 oz/acre rate was applied pre-emergence followed by a post-emergence application of Clearpath at a 0.5 lb/acre rate providing excellent pre- and post-emergence control of weeds. On 23 April, ammonium sulfate was applied at 50 lb/acre to stimulate growth and recovery from a week of unusually cool, rainy days. Using the N-STaR recommendation, all remaining N for the season was applied in a single application pre-flood since the field met the required conditions for this method. Urea + NBPT was applied at a rate of 174 lb/acre on 26 May. Once the permanent flood was established, flood levels were maintained well throughout the season. Stratego at 19 oz/acre was applied on 26 June as a preventative treatment for neck blast. No insecticide treatments were required for rice stink bug control. On 16 September, sodium chlorate at 1 gal/acre was applied as a harvest aid treatment. The rice was harvested on 20 September, yielding 205 dry bu/acre (13% moisture). The milling yield was 65/70. Total rainfall for the season was 22.4 inches.

The zero-grade, 47-acre Desha County field was located just east of McGehee on a Sharkey/Desha clay soil. Conventional tillage practices were performed following the field being fallow in 2013 due to land forming. RiceTec XL753 was drill-seeded at a rate of 23 lb/acre on 6 May. CruiserMaxx Rice insecticide seed treatment was applied to the seed in addition to the company's standard seed treatment. Roundup and Sharpen herbicides were tank-mixed for burndown and as pre-emergence herbicides. Rice emergence was observed on 22 May with 6 plants/ft^2. A second pre-emergence application of Command and Facet herbicides was tank-mixed and applied on 25 May for grass weed control. Ammonium sulfate was applied as a starter fertilizer on 26 May. A post-emergence application of Permit Plus was made on 13 June. The flood was delayed approximately 3 weeks due to the installation of underground irrigation. Residual herbicide activity held weeds and grasses to a minimum. Nitrogen fertilizer in the form of NBPT coated urea was applied at 200 lb/acre according to N-STaR recommendations. The late-boot urea application of 70 lb/acre was applied 17 July. The field was harvested 15 September and yielded 177 bu/acre with a milling yield of 57/68. The average harvest moisture was 17%. The irrigation amount averaged 30.0 acre-inches and the rainfall amount for the growing season was 10.6 inches.

The 50-acre Jefferson County field was located just off the Arkansas River south of Altheimer on a Perry clay soil. Soybean was the previous crop and conventional tillage practices were used for field preparation. The field was drill-seeded with LaKast at 65 lb/acre. Touchdown and Command herbicides were applied for burndown and as a pre-emergence on 25 May. Diammonium phosphate (18-46-0) and Potash (K_2O, 0-130-0) were applied according to soil-test recommendations. Emergence was observed on 14 June with 16 plants/ft^2. Propanil and Sharpen were applied 20 June for pre- and post-emergence broadleaf weed and grass control. Using the N-STaR recommendation, a single pre-flood fertilizer application was made of urea plus NBPT at 260 lb/acre. Irrigation amounts were 41 acre-inches and rainfall was 12.3 inches. The field maintained a good flood and looked good all year. High straight-line winds lodged 50% of the field in the late fall. The field was harvested late in the year on 17 October. The yield was a disappointing 176 bu/acre. The milling yield was 58/68 and average harvest moisture was 16%. The grower's comment was the yield was still 40-50 bu/acre better than the field's previous history.

The precision-graded 65-acre Lawrence County field was located northeast of Walnut Ridge on a Dubbs silt loam soil. The previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the fall. A pre-plant fertilizer based on soil test analysis was applied on 28 March at the recommended rate of 0-46-60 (lb/acre $N-P_2O_5-K_2O$). On 13 April, the conventional variety Mermentau was drill-seeded into a stale seedbed at 80 lb/acre. Rice emergence was observed on 25 April and consisted of 24 plants/ft^2. Obey herbicide at 32 oz/acre was applied pre-emergence on 17 April followed on 19 May by a post-emergence application of RiceBeaux (4 qt/acre) and Permit Plus (0.75 oz/acre). Excellent pre- and post-emergence control of weeds was provided. Using the N-STaR recommendation, urea + NBPT at 261 lb/acre was applied preflood on 21 May. Once the permanent flood was established, flood level was maintained sufficiently throughout the season but not without some difficulty due to the permeable nature of the field. A mid-season N application of urea at 100 lb/acre was made on 23 June. Quadris at 10 oz/acre was applied on 12 July for control of sheath blight and after which no further fungicide applications were necessary. No insecticide treatments were required for rice stink bug control. Harvest began on 4 September and 40 acres of the field was harvested. On 5 September, sodium chlorate at 1 gal/acre was applied as a harvest aid treatment on the remaining 25 acres. Harvest resumed on 8 September. The yield average for the field was 186 bu/acre. The milling yield was 61/71. Total rainfall for the season was 19.9 inches.

The 29-acre Lee County field was located just east of Moro on a Calloway silt loam soil. Soybean was the previous crop grown on the field and conventional tillage practices were used for field preparation in early spring. A pre-plant fertilizer blend of 0-60-60-10 (lb/acre N-P_2O_5-K_2O-Zn) was applied in the spring according to soil-test recommendations. Command was applied on 18 April as a pre-emergence herbicide. On 18 April, Roy J treated with CruiserMaxx Rice insecticide seed treatment was drill-seeded at 65 lb/acre. Emergence was observed on 29 April with 16 plants/ft^2. Facet, Propanil, and Permit were applied as pre-emergence and post-emergence herbicides on 14 May. Based on N-STaR recommendations, pre-flood urea + NBPT was applied at 170 lb/acre on 28 June. Using multiple-inlet irrigation a minimal flood was maintained throughout the growing season. Midseason urea fertilizer was applied on 24 June at 100 lb/acre. The field was harvested on 19 September yielding 184 bu/acre with an average harvest moisture of 20% and a milling yield of 63/71 The season-long rainfall total was 14.8 inches and irrigation amounts averaged 30 acre-inches.

The precision-graded, 67-acre Lincoln County field was located near Fresno on a Portland/Perry clay soil. Conventional tillage practices were performed following the previous crop of soybean. On 7 May, RiceTec XL753 (treated with CruiserMaxx Rice and RiceTec's standard seed treatment) was drill-seeded at a rate of 28 lb/acre. Rice emergence was observed on 21 May and consisted of 8 plants/ft^2. Due to wind and weather conditions herbicide applications were delayed 21 days. Facet, Command, and SuperWham herbicides were applied on 28 May to control heavy pressure from barnyardgrass, broadleaf signalgrass, and dayflower. On 5 June, ammonium sulfate and diammonium phosphate (DAP;18-46-0) fertilizers were applied as a starter and according to soil-test recommendations. Nitrogen in the form of urea + NBPT was applied at 240 lb/acre on 6 June according to the N-STaR recommendation. An adequate flood level was maintained throughout the season. Clincher herbicide was applied on the north 25 acres to suppress barnyardgrass escapes. The late-boot N application was applied as urea on 1 August at 70 lb/acre. Sheath blight was observed at threshold levels on 1 August and Quilt Xcel fungicide was applied. The field was harvested on 9 September and yielded 193 bu/acre with a milling yield of 65/73 and an average harvest moisture of 19%. Rainfall total for the growing season was 9.9 inches. Irrigation amounts totaled 14.3 acre-inches. Even though there was weather-delayed herbicide application and some barnyardgrass escapes were present, the grower was pleased with the yield.

The 35-acre zero-grade Lonoke County field was located south of England on a Perry silty clay soil. No tillage practices were performed on the field from the previous rice crop. The variety CL151 treated with CruiserMaxx Rice and zinc was drill-seeded at 65 lb/acre. Roundup and Command herbicides were applied 6 May. Rice emergence was observed on 19 May with 16 plants/ft^2. On 27 May, Newpath, RiceBeaux, and Command were applied as post-emergence herbicides. Diammonium phosphate (18-46-0) fertilizer was applied 28 May according to soil-test recommendations. Clearpath and Propanil herbicides were applied 10 June. Nitrogen in the form of NBPT coated urea was applied according to the N-STaR recommendation at 200lb/acre on 17 July. An adequate flood was maintained throughout the growing season. The midseason urea fertilizer application was made 28 July. Sheath blight was at threshold levels and Stratego fungicide was applied on 28 July. The field was harvested on 1 October with a yield of 188 bu/acre, a milling yield of 65/72 and a harvest moisture of 18%. The rainfall for the growing season totaled 14.5 inches and irrigation amounts totaled 25.5 acre-inches.

The precision-graded, 30-acre Monroe County field was located just south of Monroe on a Grenada silt loam soil. Conventional tillage practices were used for field preparation in the spring and rice was the previous crop. The variety Roy J treated with Apron XL and Maxim was broadcast-seeded at 90 lb/acre. Emergence was observed on 18 May at 17 plants/ft^2. Diammonium phosphate (18-46-0) fertilizer was applied at 100 lb/acre on 8 May according to soil-test recommendations. SuperWham and League herbicides were applied on 23 May. Facet and the sequential application of League herbicides were applied 10 May. Nitrogen in the form of NBPT-coated urea fertilizer was applied 12 May at 190 lb/acre according to the N-STaR recommendation. The midseason urea application was made on 9 July at 100 lb/acre. An adequate permanent flood was maintained throughout the growing season. The field was harvested 29 September and yielded 150 bu/acre. The grower stated that's about his average yield for this particular farm. Rainfall amounts totaled 14.8 inches and irrigation averaged 30 acre-inches.

The 33-acre, zero-grade Prairie County field was located southeast of Biscoe on a Sharkey clay soil. No tillage practices were performed on the field following the previous rice crop. Non-treated Roy J seed was water-seeded into a 1-inch flood on 17 April at 115 lb/acre. After the water dropped, Roundup PowerMax and Sharpen herbicides were applied for cattails, broadleaves, and aquatics. Emergence was observed 29 April when the rice pegged down and consisted of 30 plants/ft^2. Urea fertilizer was applied at 100 lb/acre on 27 May. After the rice pegged, a very shallow flood was established and the water level was brought up as plant height increased. Flooding from the adjacent Cache River complicated flood maintenance and N fertilization during the early rice growth. Nitrogen in the form of urea and DAP (18-46-0) was applied on 3 June. Diammonium phosphate was added because the soil test recommended phosphorus fertilization. On 18 June, Rebel EX herbicide was applied. Another 100 lb/acre of urea was applied 19 June to complete the N fertility program on the field. Blast was observed in the field and a Stratego fungicide application was made on 23 July. The rainfall total for the growing season was 14.2 inches. The field was harvested 9 September yielding 193 bu/acre and milling 56/70. The producer was expecting 160-170 bu/acre. He was very happy with the outcome.

The 77-acre St. Francis County field was located just south of Pine Tree on a Henry silt loam soil. Conventional tillage practices were utilized and the previous crop was soybean. Preplant fertilizer was applied at 18-46-90-10 (lb/acre N-P_2O_5-K_2O-Zn) lb/acre according to soil-test recommendations on 10 April. The variety was Mermentau treated with CruiserMaxx Rice insecticide seed treatment and drill-seeded at 78 lb/acre. Rice emergence was observed April at a stand count of 27 plants/ft^2. Roundup, Command, and League were applied as burndown and pre-emergence herbicides on 12 April. With continual rains, residual herbicide activity was observed for 45 days. Facet and a sequential application of League were applied on 28 May. Preflood urea fertilizer coated with NBPT was applied at 270 lb/acre on 29 May. An adequate flood was maintained throughout the growing season and polypipe multiple-inlet irrigation was utilized. Midseason urea fertilizer was applied at 100 lb/acre on 15 June. The field was harvested 10 September yielding 164 bu/acre with an average harvest moisture of 19% and a milling yield of 67/71. Rainfall amount for the season was 12.5 inches while the irrigation amount totaled 19.5 acre-inches.

The precision-graded, 45-acre White County field was located southeast of Bald Knob on a DeWitt silt loam soil. The previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation and conducted on 19 April. A preplant fertilizer based on soil-test recommendations was applied on 5 May at the rate of 0-36-72 (lb/acre N-P_2O_5-K_2O). On 13 April, Cheniere, treated with NipsIt INSIDE and Release, was drill-seeded at 72 lb/acre and emerged on 15 May with a stand density of 18 plants/ft^2. Command at 16 oz/acre plus glyphosate at 1 qt/acre were applied as burndown and pre-emergence herbicides on 10 May followed by an application of 2,4-D at 1.5 pt/acre on 10 July. Excellent pre- and post-emergence control of weeds was provided and no additional herbicide treatment was needed. Using the N-STaR recommendation, Urea + NBPT at 145 lb/acre was applied pre-flood on 22 June. Once the permanent flood was established, flood levels were maintained throughout the season. Surface water from a reservoir was the only water source. A midseason application of urea at 100 lb/acre was made on 15 July. No fungicide or insecticide applications were required for control of disease or insects. On 24 September, sodium chlorate at 1 gal/acre was applied as a harvest aid treatment. Harvest began on 27 September. The field yield averaged 168 bu/acre with a milling yield of 58/67. Total rainfall for the season was 14.4 inches.

The conventionally leveled, 37-acre Yell County field was located south of the Arkansas River and west of Petit Jean State Park on a Roellen silty clay soil. The previous crop grown on the field was soybean. Following a period of spring flooding, Mermentau at 90 lb/acre treated with CruiserMaxx Rice was no-till drill-seeded on 12 May. Based on soil-test recommendations, no preplant fertilizer was applied. A pre-emergence application of Obey at 52 oz/acre was made at planting. Sharpen herbicide at 1 oz/acre was applied post-emergence on 27 May followed by an application of 2,4-D at 1 qt/acre on 24 June. Excellent pre- and post-emergence control of weeds was provided and no additional herbicide treatment was needed. Using the N-STaR recommendation, urea + NBPT at 250 lb/acre was applied preflood on 10 June. The N-STaR soil test recommended preflood urea at the rate of 270 lb/acre but it was discovered late in the season that an error was made during application that reduced the rate to

250 lb/acre. Once the permanent flood was established, flood levels were maintained sufficiently throughout the season. A midseason application of urea at 100 lb/acre was made on 5 June. A preventative treatment was made for false smut using Tilt at 6 oz/acre on 31 July. No insecticide treatments were required. Harvest began on 25 October. The field had an average yield of 183 bu/acre and milled 56/68. Total rainfall for the season was 19.1 inches.

SIGNIFICANCE OF FINDINGS

Data collected from the 2014 RRVP reflect the general trend of increasing rice yields and above average returns in the 2014 growing season. Analysis of this data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

ACKNOWLEDGMENTS

We appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the rice check-off funds administered by the Arkansas Rice Research and Promotion Board. We appreciate the cooperation of all participating County Extension Agents. We also thank the professors, specialists, and program associates of the University of Arkansas System Division of Agriculture's Agricultural Experiment Station and Cooperative Extension Service and the district administration for their support.

Table 1. Agronomic information for fields enrolled in the 2014 Rice Research Verification Program.

Field Location by County	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling Yield[a]	Harvest moisture
		(acres)		(lb/acre)	(plants/ft^2)				(bu/acre)	(HR / TR)	(%)
Arkansas	RT CL XL745	78	Soybean	19	6	4 April	14 April	29 Aug	222	60/71	19
Chicot #1	RT XL753	74	Fallow	24	6	23 April	3 May	28 Aug	188	58/70	21
Chicot #2	RT XL753	60	Soybean	26	7	21 April	1 May	4 Sept	252	59/72	19
Clay	CL151	76	Soybean	70	20	3 May	13 May	20 Sept	205	65/70	20
Desha	RT XL753	47	Fallow	23	6	6 May	22 May	9 Sept	177	57/68	17
Jefferson	LaKast	50	Soybean	65	16	25 May	4 June	17 Oct	176	58/68	16
Lawrence	Mermentau	65	Soybean	80	24	13 April	25 April	5 Sept	186	61/71	18
Lee	Roy J	29	Soybean	65	16	7 May	21 May	19 Sept	184	63/71	20
Lincoln	RT XL753	31	Soybean	28	8	30 April	11 May	9 Sept	193	65/73	19
Lonoke	CL151	35	Rice	65	16	6 May	19 May	1 Oct	188	65/72	18
Monroe	Roy J	30	Rice	90	17	8 May	18 May	29 Sept	150	56/70	15
Prairie	Roy J	33	Rice	115	30	17 April	29 April	9 Sept	193	56/70	19
St. Francis	Mermentau	77	Soybean	78	27	11 April	29 April	10 Sept	164	67/71	19
White	Cheniere	44	Soybean	72	18	5 May	15 May	27 Sept	168	58/67	12
Yell	Mermentau	37	Soybean	90	20	12 May	22 May	25 Oct	183	56/68	13
Average	-----	51	-----	[b]	[c]				189	59/70	17

[a] Head rice milling yield (%) / Total rice milling yield (%).

[b] Seeding rates averaged 79 lbs/acre for conventional cultivars and 24 lbs/acre for hybrid cultivars.

[c] Stand density averaged 20 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

Table 2. Soil-test results, fertilization program, and soil classification for fields enrolled in the 2014 Rice Research Verification Program.

Field location by county	Soil test				Applied fertilizer			Soil classification
	pH	P[a]	K[a]	Zn[a]	Early[b] N-P-K-Zn-S[a]	Urea (46% N) rates applied by timing[c, d]	Total N rate[e]	
	(lb/acre)							
Arkansas	6.6	27	124	7.6	24-50-60-10-21	225*-0-70	147†	Dewitt/Arkansas silt loam
Chicot #1	6.8	40	610	8.4	18-46-0-0-0	288*-0-70	140†	Perry clay
Chicot #2	6.7	39	590	6.9	24-0-0-0-21	354*-0-0	174	Perry cay
Clay	6.2	28	188	8.0	10-40-60-0-12	174*-0-0	86†	Jackport silty clay loam
Desha	6.4	22	940	5.5	70-0-0-0-21	200*-0-70	156†	Sharkey/Desha clay
Jefferson	5.6	85	258	6.6	18-46-130-0-0	260*-0-0	128†	Perry clay
Lawrence	6.8	108	236	10.0	0-46-60-0-0	261*-100-0	166†	Dewitt silt loam
Lee	7.1	44	192	6.0	0-60-60-10-0	170*-100-0	124†	Calloway silt loam
Lincoln	6.7	26	738	5.2	24-0-0-0-21	240*-0-70	154†	Portland/Perry clay
Lonoke	6.7	47	713	4.7	18-46-0-0-0	200*-100-0	146†	Perry silty clay
Monroe	7.8	91	301	5.9	18-46-0-0-0	190*-0-100	142†	Grenada silt loam
Prairie	6.1	26	276	4.2	18-46-0-0-0	100-100-100	146	Sharkey soils
St. Francis	7.2	80	162	4.3	18-46-90-0-0	270*-100-0	178	Henry silt loam
White	5.6	48	332	3.2	0-36-72-0-0	145*-100-0	113†	Dubbs silt loam
Yell	6.0	40	350	9.0	0-0-0-0-0	250*-100-0	161†	Roellen silty clay

[a] N = nitrogen, P = phosphorus, K = potassium, Zn = zinc, and S = sulfur.

[b] N-P_2O_5-K_2O-Zn-S (includes seed treatments and preplant applications).

[c] Timing: preflood – midseason – boot.

[d] Values with an (*) indicate urea was treated with a product containing NBPT to minimize N loss due to ammonia volatilization.

[e] Values with an (†) indicate fields fertilized according to N-STaR recommendations.

Table 3. Summary of revenue and expenses per acre for fields enrolled in the 2014 Rice Research Verification Program.

Receipts	Arkansas	Chicot #1	Chicot #2	Clay	Desha	Jefferson	Lawrence	Lee
	(bu/acre)							
Yield	222	188	252	205	177	176	186	184
	($)							
Price received	5.58	5.47	5.61	5.64	5.33	5.35	5.60	5.65
Total crop revenue	**1237.99**	**1028.26**	**1413.59**	**1155.18**	**943.31**	**942.33**	**1043.91**	**1039.72**
Operating expenses								
Seed	140.28	144.79	156.86	72.80	138.76	48.30	37.60	48.30
Fertilizers and nutrients	143.01	79.82	86.85	84.87	67.58	114.06	105.89	101.18
Chemicals	84.62	72.52	54.42	72.13	59.38	39.51	123.59	63.30
Custom applications	50.75	39.90	44.10	54.18	56.00	24.50	53.27	32.90
Diesel fuel	35.67	22.80	21.53	28.32	24.32	35.87	36.83	27.89
Repairs and maintenance	34.54	23.38	26.82	31.42	29.39	44.71	52.36	32.38
Irrigation energy costs	36.53	16.44	37.44	116.07	14.42	30.40	116.07	103.53
Labor, field activities	14.27	7.80	8.41	10.28	9.34	13.35	16.68	12.09
Other inputs and fees, pre-harvest	12.82	15.29	15.98	22.41	15.09	14.93	24.12	16.62
Post-harvest expenses	129.54	109.70	147.04	119.46	103.28	102.70	108.75	107.36
Total operating expenses	**682.03**	**532.44**	**599.44**	**611.94**	**517.58**	**468.33**	**675.15**	**545.54**
Returns to operating expenses	**555.97**	**495.82**	**814.15**	**543.24**	**425.73**	**474.00**	**368.76**	**494.18**
Capital recovery and fixed costs	92.34	62.13	70.18	98.71	85.25	142.74	145.20	102.45
Total specified expenses[a]	**774.37**	**594.57**	**669.63**	**710.65**	**602.82**	**611.07**	**820.35**	**648.00**
Returns to specified expenses	**463.63**	**433.69**	**743.96**	**444.53**	**340.49**	**331.26**	**223.56**	**391.73**
Operating expenses/yield unit	3.07	2.83	2.38	2.99	2.92	2.66	3.62	2.96
Total expenses/yield unit	3.49	3.16	2.66	3.47	3.41	3.47	4.40	3.52

continued

Table 3. Continued.

Receipts	Lincoln	Lonoke	Monroe	Prairie	St. Francis	White	Yell	Average
	(bu/acre)							
Yield	193	188	150	193	164	168	183	189
	($)							
Price received	5.82	5.76	5.42	5.42	5.75	5.30	5.30	5.53
Total crop revenue	**1,122.38**	**1,082.46**	**813.01**	**1,046.07**	**942.92**	**888.11**	**968.64**	**1,044.53**
Operating expenses								
Seed	168.93	85.87	48.06	48.82	57.95	43.13	42.30	85.52
Fertilizers and nutrients	105.34	99.63	97.29	94.12	139.50	89.25	68.83	98.48
Chemicals	121.10	136.23	61.78	99.84	56.44	26.69	72.00	76.24
Custom applications	65.80	56.00	41.30	56.00	39.90	44.40	55.50	47.43
Diesel fuel	27.84	22.86	35.42	16.03	27.13	26.91	21.82	27.41
Repairs and maintenance	29.50	30.83	38.05	27.92	28.01	40.84	35.07	33.68
Irrigation energy costs	22.60	7.96	131.99	22.19	30.82	22.93	22.93	48.82
Labor, field activities	10.20	8.04	13.03	5.81	10.30	11.81	9.93	10.76
Other inputs and fees, pre-harvest	18.70	10.63	16.70	8.80	15.87	13.87	14.33	15.74
Post-harvest expenses	112.62	109.70	87.53	112.62	95.69	97.84	106.55	110.02
Total operating expenses	**682.64**	**567.74**	**571.13**	**492.14**	**501.61**	**417.67**	**446.26**	**554.11**
Returns to operating expenses	**439.74**	**514.72**	**241.87**	**553.92**	**441.31**	**470.45**	**522.38**	**490.42**
Capital recovery and fixed costs	78.51	83.24	125.52	86.76	76.12	120.39	105.98	98.37
Total specified expenses[a]	**761.15**	**650.98**	**696.65**	**578.90**	**577.74**	**538.06**	**552.25**	**652.48**
Returns to specified expenses	**361.23**	**431.48**	**116.35**	**467.16**	**365.19**	**350.06**	**416.40**	**392.05**
Operating expenses/yield unit	3.54	3.02	3.81	2.55	3.06	2.49	2.44	2.96
Total expenses/yield unit	3.94	3.46	4.64	3.00	3.52	3.21	3.02	3.49

[a] Does not include land costs, management, or other expenses and fees not associated with production.

Table 4. Herbicide rates and timings for fields enrolled in the 2014 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	(Trade name and product rate/acre)[a]	
Arkansas	Clearpath (0.5 lb) + Prowl (2.1 pts)	Newpath (4 oz) + Permit Plus (0.75) + COC (1 pt)
Chicot #1	Roundup (1 qt) + League (3.2 oz) + Command (0.66 pt)	Facet (0.5 lb) + Permit (1 oz) + League (3.2 oz)
Chicot #2	Roundup (1 qt) + League (3.2 oz) + Command (1.25 pt)	Facet (0.33 lb) + League (3.2 oz)
Clay	Command (12.8 oz)	Clearpath (0.5 lb) + COC (1 pt)
Desha	Roundup PowerMax (26 oz) + Sharpen (1 oz) + MSO (1 pt) fb Command (1 pt) + Facet (0.5 lb)	Permit Plus (0.75) + COC (1 pt)
Jefferson	Touchdown (30 oz) + Command (1.2 pts)	Propanil (4 qts) + Sharpen (1 oz)
Lawrence	Obey (32 oz)	Rice beaux (4 qts) + Permit Plus (0.75 oz)
Lee	Command (10.66 oz)	Propanil (4 qts) + Facet (0.66 lb) + Permit (1 oz)
Lincoln	Facet (0.5 lb) + Command (12.8 oz) + Super Wham (3 qt)	Permit Plus (0.75 oz) fb Clincher (15 oz) + COC (1 pt)
Lonoke	Roundup (1 qt) + Command (1 pt)	Newpath (4 oz) + RiceBeaux (2.5 qts) + Command (1 pt) fb Clearpath (0.5 lb) + Propanil (2 qts)
Prairie	Roundup Power Max (3 qts) + Sharpen (1 oz) + MSO (1 pt)	Rebel EX (20 oz) + COC (1 pt)
Monroe	Superwham (3 qts) + League (3.2 oz) + COC (1 pt)	Facet (0.33 lb) + League (3.2 oz) + COC (1 pt)
St. Francis	Roundup (1 qt) + Command (12.8 oz) + League (3.2 oz)	Facet (0.33 lb) + League (3.2 oz)
White	Glyphosate (1 qt) + Command (1 pt)	2,4-D Amine (1.5 pt)
Yell	Obey (52 oz)	Sharpen (1 oz) fb 2,4-D Amine (1 qt)

[a] The abbreviation 'fb' stands for 'followed by' and is used to separate herbicide application events.

Table 5. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2014 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field location by county[a]	Fungicide and/or insecticide seed treatment for control of diseases and insects attacking seedling rice	Fungicide applications for control of sheath blight/kernel smut/ false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(trade name and product rate/cwt seed)	----(trade name and product rate/acre)----			
Arkansas	CruiserMaxx Rice (7fl oz) +RTSTz	------	------	-------	Lambda cy (4 oz)
Chicot #1	CruiserMaxx Rice (7fl oz) + RTST	------	------	------	Mustang Max (4 oz)
Chicot # 2	CruiserMaxx Rice (7fl oz) + RTST	------	------	------	------
Clay	CruiserMaxx Rice (7 fl oz)	-----	Stratego (19 oz)	------	------
Desha	RTST	------	------	------	------
Jefferson	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Lawrence	CruiserMaxx Rice (7fl oz)	Quadris (10 oz)	------	------	------
Lee	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Lincoln	RTST	Quilt Xcel (18 oz)	------	------	------
Lonoke	CruiserMaxx Rice (7 fl oz) + Zinc (8 fl oz)	Stratego (19 oz)	------	------	------
Monroe	Apron XL (0.64 fl oz) + Maxim 4 FS (0.12 fl oz)	------	------	------	------
Prairie	------	Stratego (19 oz)	------	------	------
St. Francis	CruiserMaxx Rice (7 fl oz)	------	------	------	------
White	Nipsit Inside + Release LC (2 oz)	------	------	------	------
Yell	CruiserMaxx (7 fl oz)	Tilt (6 oz)	------	------	------

[a] RTST refers to 'RiceTec Seed Treatment' and is used to define those fields whose seed was treated by RiceTec, Inc. prior to seed purchase. Seed was treated with compounds intended to enhance germination and early-season plant growth.

Table 6. Rainfall and irrigation information for fields enrolled in the 2014 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + irrigation
	(inches)	(acre-inches)	(inches)
Arkansas	14.5	21.0	35.5
Chicot #1	21.5	10.5	32.0
Chicot #2	20.5	10.0	30.5
Clay	22.4	30.0*	52.4*
Desha	10.6	30.0	40.6
Jefferson	12.3	41.1	53.6
Lawrence	19.9	30.0*	49.9*
Lee	14.8	30.0	44.8
Lincoln	9.9	14.3	24.2
Lonoke	14.5	25.5	40.0
Monroe	14.8	30.0	44.8
Prairie	14.2	30.0	44.2
St. Francis	12.5	19.5	32.0
White	14.4	30.0*	44.4*
Yell	19.1	30.0*	49.1*
Average	15.7	23.8	38.4

[a] Not all fields were equipped with flow meters to monitor water use for irrigation. For those fields, the 5-year RRVP average of 30 acre-inches was used, and irrigation amounts using this average are followed by an asterisk (*).

Table 7. Operating costs, total costs, and returns for fields enrolled in the 2014 Rice Research Verification Program.

County	Operating costs	Operating costs	Returns to operating costs	Fixed costs	Total costs	Returns to total costs	Total costs
	($/acre)	($/bu)	----------------------	($/acre)	----------------------		($/bu)
Arkansas	682.03	3.07	555.97	92.34	774.37	463.63	3.49
Chicot #1	532.44	2.83	495.82	62.13	594.57	433.69	3.16
Chicot #2	599.44	2.38	814.15	70.18	669.63	743.96	2.66
Clay	611.94	2.99	543.24	98.71	710.65	444.53	3.47
Desha	517.58	2.92	425.73	85.25	602.82	340.49	3.41
Jefferson	468.33	2.66	474.00	142.74	611.07	331.26	3.47
Lawrence	675.15	3.62	368.76	145.20	820.35	223.56	4.40
Lee	545.54	2.96	494.18	102.45	648.00	391.73	3.52
Lincoln	682.64	3.54	439.74	78.51	761.15	361.23	3.94
Lonoke	567.74	3.02	514.72	83.24	650.98	431.48	3.46
Monroe	571.13	3.81	241.87	125.52	696.65	116.35	4.64
Prairie	492.14	2.55	553.92	86.76	578.90	467.16	3.00
St. Francis	501.61	3.06	441.31	76.12	577.74	365.19	3.52
White	417.67	2.49	470.45	120.39	538.06	350.06	3.21
Yell	446.26	2.44	522.38	105.98	552.25	416.40	3.02
Average	554.11	2.96	490.42	98.37	652.48	392.05	3.49

Table 8. Selected variable input costs per acre for fields enrolled in the 2014 Rice Research Verification Program.

County	Rice variety	Seed	Fertilizers and Nutrients	Herbicides	Insecticides	Fungicides and other	Diesel fuel	Irrigation energy costs
Arkansas	RT CL XL745	140.28	143.01	73.70	10.92	---	35.67	36.53
Chicot #1	RT XL753	144.79	79.82	66.12	6.40	---	22.80	16.44
Chicot #2	RT XL753	156.86	86.85	54.42	---	---	21.53	37.44
Clay	CL151	72.80	84.87	41.96	---	30.17	28.32	116.07
Desha	RT XL753	138.76	67.58	55.93	---	3.45	24.32	14.42
Jefferson	LaKast	48.30	114.06	39.51	---	---	35.87	30.40
Lawrence	Mermentau	37.60	105.89	94.84	---	28.75	36.83	116.07
Lee	Roy J	48.30	101.18	63.30	---	---	27.89	103.53
Lincoln	RT XL753	168.92	105.34	91.67	---	29.43	27.84	22.60
Lonoke	CL151	85.87	99.63	109.51	---	26.72	22.86	7.96
Monroe	Roy J	48.06	97.29	61.78	---	---	35.42	131.99
Prairie	Roy J	48.82	94.12	73.12	---	26.72	16.03	22.19
St Francis	Mermentau	57.95	139.50	56.44	---	---	27.13	30.82
White	Cheniere	43.13	89.25	24.53	---	2.16	26.91	22.93
Yell	Mermentau	42.30	68.83	66.60	---	5.40	21.82	22.93
Average	**-----**	**85.52**	**98.48**	**64.89**	**8.66**	**19.10**	**27.41**	**48.82**

Molecular Analysis for the Development of Rice Varieties

V.A. Boyett, V.I. Thompson, V.L. Booth, K.A.K. Moldenhauer, G.L. Berger, X. Sha, D.K.A. Wisdom, J.M Bulloch, and H. Sater

ABSTRACT

Molecular analysis in the development of new rice varieties has been in use at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark., for over 14 years. During this time, much effort has been devoted to the phenotypic and genotypic characterization of parental lines and progeny in the areas of new long-grain and medium-grain cultivar development, hybrid rice breeding, backcross populations, aromatic rice breeding, genomic mapping of specific traits, and seed purification.

In 2014, materials from the RREC rice breeding programs were characterized on a molecular level. Molecular analysis was performed on 14 different projects from 7 distinct research programs. These projects included marker-assisted selection with markers linked to agronomic traits of interest, DNA fingerprinting across the genome for confirming seed purity and genotype prior to commercial release of a new cultivar, and fingerprinting for assessing progress in reducing trait segregation in the hybrid rice breeding program. Of the over 35,000 data points generated during 2014, 11% were for identification and seed purity assessments, 12% were for molecular mapping of a particular trait, and the remaining 77% were for the purpose of DNA marker-assisted selection to enhance the development of new cultivars generated in the rice breeding programs.

INTRODUCTION

Since the mid-1990s, tremendous advances have been gained in improving techniques and throughput for DNA marker-assisted selection (MAS). Marker-assisted selection is a tool for the rice breeder to achieve greater efficiency and increase the probability of success during the process of developing new cultivars. Areas in which MAS enhances conventional breeding techniques include marker analysis of parental materials, backcrossing schemes, pyramiding multiple genes, early generation selection, and combination with phenotypic assessments (Collard and Mackill, 2008). Most importantly, using DNA markers can save time and resources by simplifying the screening process and allowing selection of single plants and selection to occur at early seedling stages (Collard and Mackill, 2008).

Desirable DNA markers should be able to detect a high frequency of polymorphism, exhibit codominance, be abundant and enable whole genome coverage, and have high duplicability. Ideal markers for MAS have to be suitable for high-throughput analysis and multiplexing, be cost-effective, require only small amounts of DNA, and be user friendly. Factors to consider when choosing DNA markers are the number of alleles, polymorphism information content (PIC) value, and whether or not they are informative for a particular breeding population (Xu, 2003).

In 2014, materials from the RREC rice breeding programs were screened with simple sequence repeat (SSR) markers linked to the rice blast resistance genes *Pi-b, Pi-k, Pi-ta*, and *Pi-z* (Conaway-Bormans et al., 2003; Fjellstrom et al., 2004, 2006; Wang et al., 2010) and the cooking quality traits of amylose content, gelatinization temperature, and aroma (Bao et al., 2002; Bergman et al., 2001; McClung et al., 2004). Plant height was assessed using RM1339 linked to *sd1* (Sharma et al., 2009), and leaf texture was predicted using a glabrous-linked single nucleotide polymorphism (SNP) marker GlabSNP (pers. comm., R.G. Fjellstrom). The remaining rice SSR and SNP markers were scattered throughout the genome and used for DNA fingerprinting and background selection purposes.

The objective of this ongoing study is to apply DNA marker technology to assist with the mission of the RREC rice breeding programs. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii) performing DNA marker-assisted selection of progeny to confirm identity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

PROCEDURES

Leaf tissue from individually tagged field plants or greenhouse grown seedlings was collected in manila coin envelopes and kept in plastic bags on ice until being placed in storage at the molecular genetics lab. In some instances, seeds were germinated in Petri dishes to obtain leaf tissue. The leaf tissue was stored at -80 °C until sampled. Total genomic DNA was extracted from the embryo using a Sodium hydroxide/Tween 20 buffer and neutralized with 100mM TRIS-HCl, 2 mM EDTA (Xin et al., 2003).

Each set of DNA samples was arrayed in a 96-well format and processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, Calif.). For each 25 µl PCR analysis, 2 µl of each sample was used as the starting DNA template.

Polymerase chain reaction (PCR) analysis was performed with either HEX, FAM, or NED labeled primers and cycling the reactions in a Mastercycler Gradient S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.). To save on processing and analysis costs, PCR plates were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.), separated on an Applied Biosystems 3730 DNA Analyzer, and analyzed using GeneMapper Software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

Marker analysis of all 14 projects is summarized in Table 1. In Projects #1, 6, 11, 12, 13, and 14, results show that progress is being made toward the development of new cultivars. The percentage of segregating alleles is reduced compared to the marker data from previous generations (data not shown) and alleles for desirable traits of the particular breeding objectives are in higher abundance than the non-desirable alleles. By eliminating the materials with the non-desirable alleles in this generation, the next generation can be advanced more rapidly to a viable cultivar. In Project #10, the marker results indicated that more careful selection and at least another round of marker-assisted backcrossing is necessary to be able to progress this population further.

Projects #2, 3, 5, and 8 involved screening with various DNA "fingerprint" markers to assess seed purity of the populations. In Projects #2 and 3, a problem was suspected based on phenotypic observations. In Project #2, it was revealed that the population was a seed mixture with 42% of the samples tested coming from different varieties. Marker data confirmed that in Project #3, 8% of the samples tested were not the correct variety and 20% of the samples were segregating in a manner that suggested a possible hybrid between the off type and the correct variety. Marker analysis confirmed that the samples in Project #5 were exactly the same on a molecular level despite coming from multiple seed sources and being planted in multiple locations, thereby increasing the breeder's confidence that the population would soon be ready for commercial release. Although the samples from Project #8 were not as advanced as those in Project #5, marker analysis revealed that this population is homozygous and uniform and progressing through development.

In Project #9, a set of samples of an elite line was genotyped for one trait. The markers indicated that the desired gene was present in all samples confirming uniformity of the trait.

Project #7 is a molecular mapping project to attempt to locate the precise region of the rice genome responsible for a specific trait of interest. Marker analysis of a mapping population was conducted to determine if there was a marker-trait association. The results helped narrow the region of the genome for further study.

Markers were used in Project #4 in an attempt to identify an unknown population. Possible varieties were used as positive control samples on each analysis plate. Unfortunately, none of the 25 markers that were polymorphic between the control samples identified a match, so the identity of the population is still unknown.

SIGNIFICANCE OF FINDINGS

Marker screening of breeding materials revealed that progress is being made in the RREC rice breeding programs in reducing trait segregation and identifying promising lines to advance. Applying molecular marker technology to the rice breeding programs enabled the breeders to assess the status of the populations, and eliminate those materials that are not desirable for inclusion in future rice breeding efforts, saving time, resources, and expenses.

ACKNOWLEDGMENTS

This work was supported by funding to the UARREC provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. The authors thank A. McClung, A. Jackson, and M. Jia for promoting the Rice Genomics Program and allowing the use of equipment, facilities and supplies at the USDA-ARS Dale Bumpers National Rice Research Center.

LITERATURE CITED

Bao, J.S., H. Corke, and M. Sun. 2002. Microsatellites in starch-synthesizing genes in relation to starch physicochemical properties in waxy rice (*Oryza sativa* L.) Theor. Appl. Genet. 105:898-905.

Bergman, C.J., J.T. Delgado, A.M. McClung, and R.J. Fjellstrom. 2001. An improved method for using a microsatellite in the rice *Waxy* gene to determine amylose class. Cer. Chem. 78:257-260.

Collard, B.C.Y. and D.J. Mackill. 2008. Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. Phil. Trans. R. Soc. B 363:557-572.

Conaway-Bormans, C.A., M.A. Marchetti, C.W. Johnson, A.M. McClung, and W.D. Park. 2003. Molecular markers linked to the blast resistance gene *Pi-z* in rice for use in marker -assisted selection. Theor. Appl. Genet. 107:1014-1020.

Fjellstrom, R.G., C.A. Conaway-Bormans, A.M. McClung, M.A. Marchetti, A.R. Shank, and W.D. Park. 2004. Development of DNA markers suitable for marker assisted selection of three *Pi* genes conferring resistance to multiple *Pyricularia grisea* pathotypes. Crop Sci. 44:1790-1798.

Fjellstrom, R.G., A.M. McClung, and A.R. Shank. 2006. SSR markers closely linked to the *Pi-z* locus are useful for selection of blast resistance in a broad array of rice germplasm. Mol. Breed. 17:149-157.

McClung, A.M., M. Chen, H. Bockelman, R. Bryant, W. Yan, and R.G. Fjellstrom. 2004. Characterization of a core collection of rice germplasm and elite breeding lines in the U.S. with genetic markers associated with cooking quality. PAG XII; 2004 10-14 Jan.; San Diego, Calif.

Sharma, A., A.M. McClung, S.R.M. Pinson, J.L. Kepiro, A.R. Shank, R.E. Tabien, and R.G. Fjellstrom. 2009. Genetic mapping of sheath blight resistance QTLs within tropical Japonica rice cultivars. Crop Sci. 49:1:256-264.
Wang, X., R. Fjellstrom, Y. Jia, W.G. Yan, M.H. Jia, B.E. Scheffler, D. Wu, Q. Shu, and A. McClung. 2010. Characterization of *Pi-ta* blast resistance gene in an international rice core collection. Plant Breed. 129:491-501.
Xin, Z., J.P. Velten, M.J. Oliver, and J.J. Burke. 2003. High-throughput DNA extraction method suitable for PCR. BioTech. 34:4:820-825.
Xu, Y. 2003. Developing marker-assisted selection strategies for breeding hybrid rice. *In:* J. Janick (ed.). Plant Breeding Reviews. 23:73-174. Hoboken, N.J.: John Wiley & Sons, Inc.

Table 1. Summary of results for marker analyses of all projects in 2014.

Project	Type	Marker	Results
1	Backcross	Plant height	29% Segregating
			71% Semidwarf
		Amylose	40% Segregating; 56% Low
		RVA	100% Weak
		Gel temp	27% Segregating
			2% Low; 69% Med.-High
		Pi-b	22% Segregating
			45% Resistant
			18% Susceptible
		Pi-ta	15% Segregating
			83% Resistant
		Pi-z	100% Susceptible
		11 Fingerprint	6-45% Segregating
2	Seed purity	11 Fingerprint	42% Off type
3	Seed purity	25 Fingerprint	8% Off type
			20% Segregating
4	ID unknown	25 Fingerprint	No allele matches
5	Seed purity	30 Fingerprint	pure line
6	F_3 gen	Aroma	2% Segregating
			7% Non-aromatic
			91% Aromatic
		Amylose	13% Segregating
			35% Intermediate
			52% Low
		Pi-b	82% Susceptible
			16% Resistant
		Pi-ta	4% Segregating
			72% Susceptible
			20% Resistant
7	Mapping	8 Fingerprint	Progress finding trait locus
8	Seed purity	18 Fingerprint	Uniform population

continued

Table 1. Continued.

Project	Type	Marker	Results
9	Elite line	1 Trait	Presence of gene confirmed in all samples
10	Backcross	14 Fingerprint	Significant segregation still present
11	F_4 gen	Grain type	3% Segregating
			82% Medium; 14% Long
		RVA	100% Weak RVA
		Gel Temp	5% Segregating
			3% Medium-High; 91% Low
12	F_3 Gen	*Pi-b*	37% Segregating
			53% Susceptible
			2% Resistant
		Pi-ta	33% Segregating
			47% Susceptible
			5% Resistant
13	F_5 gen	Grain type	72% Long; 28% Medium
		Gel temp	29% Low; 71% Med-High
		Pi-b	100% Susceptible
		Pi-ta	5% Segregating
			86% Susceptible
			9% Resistant
		Pi-z	4% Segregating
			89% Susceptible
			7% Resistant
14	F_4 gen	Aroma	4% Segregating
			7% Non-aromatic
			91% Aromatic
		Grain type	9% Segregating
			34% Long; 57% Medium
		Gel temp	2% Segregating
			51% Med.-High; 45% Low
		Pi-b	100% Susceptible
		Pi-ta	72% Susceptible
			28% Resistant
		Pi-z	100% Susceptible

BREEDING AND GENETICS

Screening for Rice Blast Resistance of Uniform Rice Regional Nursery Varieties

C. Feng, F. Rotich, and J.C. Correll

ABSTRACT

The Uniform Regional Rice Nursery (URRN) collection (200 lines) was evaluated for resistant to 11 U.S. reference isolates of *Magnaporthe oryzae* in 2014. The greenhouse-obtained isolate, IB33, was the most virulent isolate, with only 6 varieties being resistant to this isolate. Isolates 49D (race IB49) and TM2 (race k) also were highly virulent with only 20% and 26% lines being resistant to these isolates, respectively. Over 70% of the lines were resistant to isolates A264 (race IC17), isolate #24 (race IG1), and isolate IB54 (race IB54). Line RU1401182 was resistant to all tested isolates, five lines (RU1402048, RU1102071, RU1402103, RU1402165, RU0603075) were resistant to 10 isolates, 36 lines were resistant to 9 isolates, and 19 lines were resistant to 8 isolates, so about 30% of the tested lines had resistance to some of the reference isolates. However, 14 lines (RU1403003, RU1401007, RU1403023, Francis, RU1403069, RU1401070, RU1301084, RU1404122, RU1401139, RU1401145, RU1404157, RU1405187, RU1401188, and RU1402195) were susceptible to all isolates; 8, 23, and 26 lines were only resistant to 1, 2, or 3 isolates; and these lines accounted for 35% of the lines tested. These results could assist breeders to make decisions on which lines show the most promise with regard to developing elite lines with high levels of resistance to the rice blast pathogen.

INTRODUCTION

Rice is one of the most important staple food crops worldwide, feeding over half of the world's population. The demand for rice increases as the world population grows. However, rice production is threatened by a number of diseases. Rice blast disease, caused by the fungus *Magnaporthe oryzae* (anamorph: *Pyricularia oryzae*), is one of the most destructive diseases of rice. Rice blast may be found in all rice production areas, and can cause severe yield loss under favorable environmental conditions. Rice blast continues to be a major production constraint in Arkasnas. Planting resistant cultivars is the most economic and effective way to manage this disease. However, the pathogen is endemic in rice production regions and many races of this pathogen exist, for examples, race IB49 and IC-17 remain the most prevalent in Arkansas (Correll et al., 2000; Xia et al., 2000), with occasional epidemics due to "race k" type isolates (Lee et al., 2005). It is necessary to know the resistance spectrum of new cultivars to the current rice blast pathogen population before they are released. This study was to test the URRN lines with 11 U.S. reference isolates of *Magnaporthe oryzae*, which are representative of the pathogen population in Arkansas.

PROCEDURES

Two hundred experimental rice lines developed by the rice breeders from Arkansas, Louisiana, Mississippi, and Texas have been tested with 11 rice blast reference isolates (Table 1). Rice cultivar M204 was included in each test, used as the susceptible control. Rice seed were planted in plastic trays filled with river sand mixed with potting soil in the greenhouse at the University of Arkansas, Fayetteville, Ark. Each tray was planted with 38 rows of URRN entrees and 2 rows of the susceptible control M204. Plants were fertilized with Miracle Gro All-Purpose Plant Food 20-20-20 once a week during each test. Plants were inoculated approximately 14 to 20 days after planting. Each isolate was grown on rice bran agar (RBA) (Correll et al., 2000) for approximately 7 to 10 days, then re-inoculated on new rice RBA for 7 to 10 days. Spores were collected in cool water, and adjusted to a concentration of 200,000 spores/ml per isolate. Each tray was inoculated with 50 ml of inoculum with an air compressor sprayer. After inoculation, the plants were incubated at 100% relative humidity in a mist chamber at approximately 22 °C for 24 h, allowed to dry for 2 to 3 h before being moved to the greenhouse. The inoculated plants were incubated in the greenhouse for 6 days. On the 7th day after inoculation, the plants were scored according to a standard 0 to 9 disease rating scale where 0 = immune and 9 = maximum disease susceptibility (Correll et al., 1998). Lines rated 0 to 3 were considered resistant, whereas those rated 4 to 9 were considered susceptible.

RESULTS AND DISCUSSION

The 200 URRN lines were tested with 11 U.S. reference isolates of *Magnaporthe oryzae*. The isolate IB33, originally recovered from rice under greenhouse conditions by F.N. Lee, was the most virulent isolate. Only 6 lines were resistant to this isolate. Isolates 49D (race IB49) and TM2 (race k) were highly virulent too, with only 41 and 53 lines (about 20% and 26% of total) resistant to these two isolates. Over 70% of the lines were resistant to isolates A264 (race IC17), isolate #24 (race IG1), and isolate

IB54 (race IB54). Isolates A119 and A598 were classified as race IB49 too. However, there were 120 lines resistant to these two isolates. The difference in virulence of the three IB49 isolates suggested they differ in their virulence characteristics. The number of lines that were resistant or susceptible to each isolate is shown in Fig. 1.

One line, RU1401182, was resistant to all tested isolates, five lines (RU1402048, RU1102071, RU1402103, RU1402165, RU0603075) were resistant to 10 isolates, RU1402048, RU1402103, RU1402165 were only susceptible to IB33. RU1102071 and RU0603075 had intermediate resistance to 49D (disease rating were 5 and 4 respectively). A total of 36 lines were resistant to 9 isolates, and 19 lines were resistant to 8 isolates, so about 30% of the tested lines showed some resistance. Fourteen lines (RU1403003, RU1401007, RU1403023, Francis, RU1403069, RU1401070, RU1301084, RU1404122, RU1401139, RU1401145, RU1404157, RU1405187, RU1401188, and RU1402195) were susceptible to all isolates; 8, 23, and 26 lines were only resistant to 1, 2, or 3 isolates, respectively, and accounted for 35% of the total tested. The 6 most resistant and 14 most susceptible lines were listed in Table 2 and the number of lines that were resistant to a certain number of isolates is shown in Fig. 2. A complete examination of the entry by isolate interactions is available on line at http://www.uark.edu/ua/jcorrell/data/2014URRNfinal.xls.

SIGNIFICANCE OF FINDINGS

The most effective and economic way for managing rice blast disease is utilizing resistant cultivars. The results from this study indicate that the URRN germplasm shows a wide range in resistance to the rice blast pathogen. Effective evaluation of advanced germplasm will help breeders to determine what lines should be released and what varieties can be chosen as parental lines for their future breeding programs. The screening efforts will ultimately help producers select rice cultivars for the most effective disease management of rice blast disease.

ACKNOWLEDGMENT

The authors would like to thank the Arkansas Rice Research and Promotion board for their financial support of the research reported.

LITERATURE CITED

Correll, J.C., Harp, T.L, and F.N. Lee. 1998. Large-scale screening of USDA rice germplasm for qualitative and quantitative resistance to two common races (IC-17 and IB-49) of the rice blast pathogen, *Pyricularia grisea*. *In:* R.J. Norman and T.H. Johnson (eds.). Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:169-194. Fayetteville, Ark.

Correll, J.C., T.L. Harp, J.C. Guerber, R.S. Zeigler, B. Liu, R.D. Cartwright, and F.N. Lee. 2000. Characterization of a population of *Pyricularia grisea* from rice in the

United States using independent genetic and molecular markers. Phytopathology 90:1396-1404.
Lee, F.N., R.D. Cartwright, Y. Jia, and J.C. Correll. 2005. *Magnaporthe grisea* race shift for virulence to the major R gene, *Pi-ta* in Arkansas. Phytopathology 95:S175.
Xia, J.Q., J.C. Correll, F.N. Lee, W.J. Ross, and D.D. Rhoads. 2000. Regional population diversity of *Pyricularia grisea* in Arkansas and the influence of host selection. Plant Disease 84:877-884.

Table 1. Background information of the 11 U. S. reference isolates of *Magnaporthe oryzae* used in this study.[a]

Isolate	Vegetative compatibility group (VCG)	MGR586 group	Mating type	RACE	Year	Location
A119	US-03	C	I	IB49	1992	AR
A264	US-02	B	II	IC17	1993	AR
A598	US-01	A	I	IB49	1992	AR
#24	US-02	B	II	IG-1	1992	AR
IB33	US-04		I	IB33		AR
IB54	US-04		I	IB54		
49D	US-03	E	II	IB49	1985	AR
ZN7	US-02	B	II	IE-1	1995	TX
ZN15	US-01	A	I	IB-1	1996	TX
ZN46	US-01	A	I	IC-1	1996	FL
TM2	US-02	B	II	race k		TX

[a] The reference isolates belong to different genetic groups based on vegetative compatibility (A-H) which also correspond to different molecular fingerprint groups (MGR586 A-H).

Table 2. Disease reactions of the most resistant (6) and susceptible (14) lines tested.

Entry	Variety	**A119** IB-49	**A264** IC-17	**A598** IB-49	**24** IG-1	**IB33** IB33	**IB54** IB54	**49D** IB-49	**ZN7** IE-1	**Zn15** IB-1	**Zn46** IC-1	**Tm2** Race k
182	RU1401182	0	0	3	0	3	0	0	0	0	3	0
48	RU1402048	0	0	0	0	5	0	3	3	0	0	2
71	RU1102071	0	0	3	0	3	0	5	0	0	3	0
103	RU1402103	0	0	0	0	5	0	0	0	0	0	3
165	RU1402165	0	0	0	0	6	0	0	0	0	0	0
199	RU0603075	0	0	0	0	3	3	4	0	0	0	0
3	RU1403003	5	4	5	5	7	6	8	5	6	6	8
7	RU1401007	5	5	6	4	7	6	7	6	6	6	7
23	RU1403023	5	4	4	4	7	6	6	5	6	6	8
40	FRNS	6	4	4	4	7	6	7	6	6	5	8
69	RU1403069	6	5	4	5	7	6	8	6	7	6	8
70	RU1401070	6	5	5	4	7	5	8	7	7	6	8
84	RU1301084	6	4	4	5	6	6	6	6	6	6	8
122	RU1404122	6	4	6	6	7	6	7	5	6	6	8
139	RU1401139	5	5	6	5	8	6	6	6	6	6	8
145	RU1401145	4	4	4	4	7	6	6	6	6	5	6
157	RU1404157	6	4	6	5	7	6	7	5	6	6	6
187	RU1405187	4	4	5	5	7	6	6	6	6	6	6
188	RU1401188	6	5	6	5	8	6	6	7	6	6	8
195	RU1402195	4	5	6	4	6	5	7	6	5	6	7

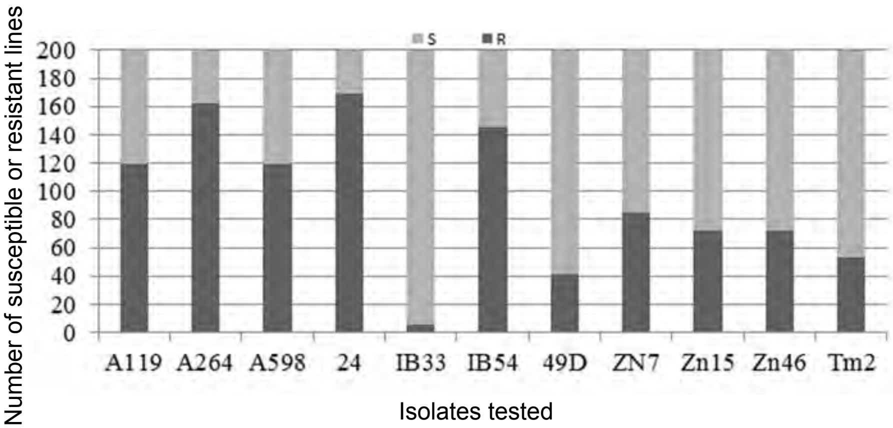


Fig. 1. Distribution of the number of varieties that were resistant (rating scale 0 to 3, 0 is most resistant) and susceptible (rating scales 4 to 9, 9 is the most susceptible) for each isolate.

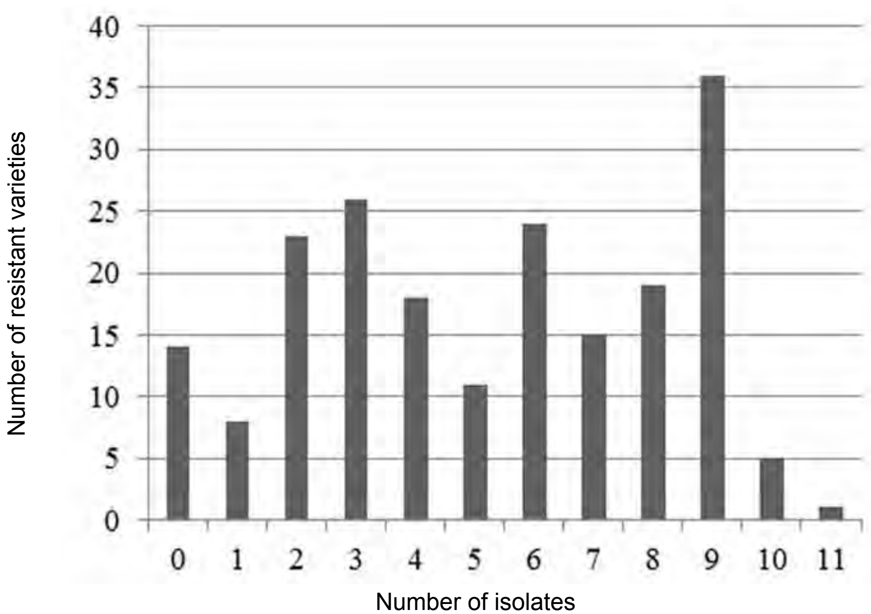


Fig. 2. Distribution of the number of varieties rated as resistant to 0 isolate, 1 isolate, 2 isolates, etc.

Rice Breeding and Pathology Technical Support

C.D. Kelsey, S.B. Belmar, K.A.K. Moldenhauer, and Y.A. Wamishe

ABSTRACT

Development of disease-resistant rice is one of the most important achievements rice breeders strive to accomplish at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The center's plant pathology group assists with this goal by screening rice germplasm, preliminary and advanced breeding lines in the greenhouse and field. Blast and sheath blight, and bacterial panicle blight are diseases currently being screened for plant resistance or susceptibility at the RREC. Artificial inoculation of these pathogens on rice is essential to collecting disease severity data. Screening for blast is conducted both in the greenhouse and the field. Screening for sheath blight is only in the field, and screening for bacterial panicle blight is mainly in the field with some selected lines evaluated in the greenhouse. Data from these tests are used by the breeding program either to transfer genes for resistance into adapted and high yielding cultivars or to select lines for further agronomic testing. The pathology technical group also supports the extension plant pathology program which has the crucial responsibility of screening for bacterial panicle blight and conducting all the applied research to provide management answers for the major prevailing and newly emerging diseases, including collaborative interdepartmental, industry, and multi-state research endeavors.

INTRODUCTION

Breeding for disease resistance is a major area of emphasis in any breeding program. At the RREC, rice breeders and pathologists work together to develop cultivars with desirable agronomic traits and disease resistance. Released rice cultivars are also evaluated every year for disease resistance due to concerns associated with evolving pathogen races. Disease evaluation of rice for major diseases starting in early generations has been an important required activity for the rice breeding program. Lines that may require further improvements for one or more traits, but have good yield, quality, or disease resistance, may be considered as parents within the breeding programs.

Rice blast [*Magnaportha grisea* (T.T. Herbert) M.E. Barr] and sheath blight (*Rhizoctonia solani* Kuhn) still remain as major diseases of rice. Bacterial panicle blight [BPB; *Burkholderia glumae* (Kurita and Tabei), formerly known as *Pseudomonas glumae*] has shifted from being minor and sporadic to an emerging disease, with many of the conventional and commercial cultivars grown in the southern U.S. rice-producing states being susceptible. This bacterial disease can result in a significant yield loss under favorable environments unless proper management practices are discovered. Currently, no chemical treatments are available for BPB control in the U.S. The disease requires answers for several unknowns related to the bacterial complexity, host-pathogen interactions, and disease spread. An excellent means of combating BPB would be the discovery of BPB resistance that could be utilized in the breeding program. Laboratory, greenhouse, and field trials need to be efficiently conducted to understand and develop sound management techniques for this disease.

The screening methodology for each of the three diseases allows the rice lines to be categorized as resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S), or very susceptible (VS). Screening for disease resistance under natural conditions may not be as reliable as artificial inoculation where all lines are exposed to uniform disease pressure. Creating a favorable environment for disease development is essential and must be done for each disease separately.

Screening for leaf blast is more successful at a seedling stage in the greenhouse than in the field. However, screening for panicle blast requires more mature plants which are easier to maintain in the field. Care needs to be taken because a blast disease epidemic requires tighter control on the environmental conditions the plants are exposed to both pre- and post-inoculation. Control of the field environment is limited so the timing of inoculation usually precedes a weather front that delivers dew or light rain conditions. Field testing also requires repeated inoculation; therefore, sizable amounts of usable inoculum must be produced in a short amount of time. Field sheath blight inoculation also requires massive amounts of inoculum that takes months of careful preparation.

Bacterial isolation and purification needs a complex partially specific media. The production of bacterial suspension for inoculation requires a constant supply of bacteria grown on a common agar media. An aseptic technique must be used in producing many uncontaminated agar plates for purification and to obtain sizable volumes of a useable bacterial suspension.

PROCEDURES

Rice Evaluation for Blast Resistance in the Greenhouse for the Breeding Program

For greenhouse testing of blast, nearly 600 entries of the Uniform Regional Rice Nursery (URRN), the Arkansas Rice Performance Trials (ARPT), the Stuttgart Initial

Test (SIT), the Clearfield Stuttgart Initial Test (CSIT) advanced lines, hybrid lines, and preliminary breeding materials were evaluated using 4 to 6 races of *M. grisea* individually per test. Seven-day old blast isolates were washed from agar plates with a xanthan gum suspension to create a standardized spore suspension of 2.0 × 10^4 spores/ml. Each test was replicated 3 times and each individual suspension was applied at the 4-leaf plant stage approximately 21 days after planting using a Badger 250-2 basic spray gun. Spray inoculated plants were immediately placed in a dew chamber for about 14 hours. Disease data were collected seven to ten days after the plants were removed from the dew chamber and placed on a greenhouse bench. A single comprehensive greenhouse test for only one blast race required 28 to 30 days. Disease evaluation used the rating scale of 0 (no disease) to 9 (severe disease).

Rice Evaluation for Blast, Sheath Blight, and Bacterial Panicle Blight Resistance in the Field for the Breeding Program

Field testing for blast and sheath blight was replicated four times. Inoculum for blast and sheath blight consisted of sterilizing several hundred gallons of cracked corn (corn chops) and ryegrass seed. Several gallons of milo were also sterilized more so for blast inoculum. The sterilization protocol to produce the inoculum carrier material required three days to process about 16 gal for sheath blight and 24 hours to process around 60 gal for blast. The cultures were grown on a specific medium for seven days. Blast cultures were mixed into the sterile chops/milo/ryegrass and this inoculum was distributed to the field within 24 hours. Sheath blight cultures were mixed into the sterile chops/ryegrass and after a week of incubation at room temperature, the sheath blight infected seed media was air dried and kept in paper bags until ready for field inoculation. Clean conditions were maintained throughout the entire process to avoid contamination.

Field tests for blast were established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., as hill plots surrounded by a spreader mixture of blast susceptible lines to encourage the buildup of spores for disease spread. A row of corn was planted on the levee as a partial windbreak. Rice plants at tillering and heading were inoculated with semi-dried seed media which contained five races of the pathogen. Plants were inoculated twice for leaf blast at the 5-leaf stage and at least twice for panicle blast starting from boot emergence. Sheath blight testing was conducted in a hill plot nursery with four replications at the RREC. Air dried inoculum that contained six isolates of the pathogen was applied to plants at the panicle initiation growth stage. Application of inoculum for both blast and sheath blight were hand-broadcasted.

Field testing for bacterial panicle blight on the URRN/ARPT was replicated twice in hill plots. One replication was inoculated using a back-pack sprayer with a bacterial suspension (~10^6 × 10^8 cfu/ml) directly on the plants between boot-split to flowering stage. The other replication was observed for natural infection. Disease data were collected from all plots using a rating scale of 0 (no disease) to 9 (severe disease).

Rice Evaluation of Diseases for the Extension Plant Pathology

In addition to screening rice germplasm for diseases, the pathology technical group provided assistance in additional applied research conducted by the rice extension plant pathology program, in the areas of greenhouse, laboratory, and field activities. Greenhouse disease evaluation for BPB included mostly preliminary studies on various methods to artificially inoculate plants at both the seedling and adult developmental stage. Tested techniques included direct seed dip, foliar spray, syringe injection of culm, a cut leaf dip, and a soil inoculation. An investigative test of entries previously tested in the 2012/2013 URRN/ ARPT with ratings of R/MR was also conducted in the greenhouse. One hundred twenty nine entries were field hand-planted and then 71 were transplanted and inoculated in the greenhouse for environment control. These entries were selected for heading time being the same.

Preliminary laboratory testing of bacterial panicle blight used leaves cut from a susceptible and a moderately resistant variety at different plant maturity stages. These leaves were needle pricked and swabbed with a bacterial suspension of 10^6 to 10^8 cfu/ml over the prick wound and placed at 30 °C for three days. Lesion development was used to indicate at what maturity stages the plant was most susceptible. However, lesion development on leaves of the same age was erratic and requires further testing. Investigations continued to determine the effects of water stress, fertility levels, seeding rate, and planting dates on bacterial panicle blight incidence and severity under field conditions. Seed for these tests were artificially inoculated in the laboratory via vacuum infiltration using a bacteria suspension of approximately 10^6 to 10^8 cfu/ml.

Field tests were also conducted in collaboration with chemical industries that included five products with a total of 22 treatments for bacterial panicle blight, three products for sheath blight with a total of 29 treatments, one early-season seedling disease containing nine treatments, one kernel smut and one false smut each with 5 treatments. All of these tests were replicated four times. The sheath blight inoculum amounted to 20,880 grams to meet the needs of industry tests. An additional 64,800 grams of inoculum was processed to meet interdepartmental collaborative activities on N-STaR by fungicide study. Kernel smut [*Tilletia horridia* (Takah), formerly known as *Tilletia barclayana*] was seed inoculated by mixing 10 g of dry spores with Roy J (susceptible seed variety) in each of twenty 77-g seed packages. False smut [*Ustilaginoidea virens* (Cke) Tak] was seed inoculated using 4 g of dry spores also mixed with Roy J in each of twenty 77-g seed packages. An additional 2 gal of spore suspensions at optical densities of approximately 94 for kernel smut and approximately 42 for false smut was mechanically sprayed. Spraying was conducted at each growth stage of boot-split, heading, and 10% to 20% flowering for both smuts. For false smut, a mist system was constructed to create a favorable condition. GP2, a very susceptible germplasm obtained from DBNNRC, was planted for a border to determine the effect of disease initiation and enhancement. The inoculum production endeavor for all tests required a substantial amount of personnel time to make the various inocula and to inoculate fields at RREC and PTRS, related to extension , industry, and N-STaR collaborative research. Disease data were collected from the respective plots and summarized for each test as each protocol required. Due to the insensitivity of propiconazole in the field (on false smut), preliminary laboratory studies were conducted to test the efficacy of chemically amended agar on false and kernel smuts. These trials will be ongoing in 2015.

RESULTS AND DISCUSSION

Field assessment of resistance to sheath blight, blast, and bacterial panicle blight for experimental rice lines across all tests was successfully completed for 2014. This year showed a large number of candidates scoring resistant or moderately resistant for panicle blast to the races tested. Unfortunately, not many lines shared the same criteria for leaf blast. A few moderately tolerant entries were observed for sheath blight (Table 1).

Field blast and sheath blight evaluations were assessed for 1083 experimental lines and checks. These lines include: 90 for the ARPT, 197 for the URRN, 15 for the RREC hybrid breeding program, 33 for the Clearfield ARPT (CARPT) test, 100 for Missouri, 176 for the Clearfield SIT (CSIT), 132 for the SIT, preliminary entries, entries of combined SIT and CSIT, 6 Aromatics and 4 long-grain advanced lines. A total of 10016 hill plots were established to include all lines replicated, inoculated, and evaluated for leaf and panicle blast. The total number of entries replicated, inoculated, and evaluated for sheath blight was 5008 hill plots.

Greenhouse screenings showed several of the 572 lines assessed for leaf blast (Table 2) to be resistant or moderately resistant. One entry, CL172, showed the most resistance to all blast races tested with no rating of any replication being above 6. Experimental lines included for screening using 6 blast races were 92 entries for the ARPT, 197 entries for the URRN, 14 entries for the RREC hybrid breeding program, and 4 advanced lines. Four races of the 6 used in aforementioned tests were used for 258 selected Preliminary lines and 6 lines from CSIT. With three replications in all tests, the total number of evaluations for leaf blast in the greenhouse for 2014 was 8712.

Field evaluations for bacterial panicle blight resistance included 200 hill plot entries of URRN and 90 hill plot entries of ARPT. The entries from 2014 URRN showed 46 as R or MR. Lines RU1102071 and RU1401142 received a rating of 0 and RU1201047 received a 1 rating using a rating scale of 0 to 9. The 2014 ARPT showed 49 entries as being R or MR. RU1201047 and RU1401145 rated at 1 on the 0 to 9 scale (Table 3, Wamishe et al., 2015). Due to differences in maturity and variability in weather during inoculation, such presumably high resistance in the field is being checked for consistency under a controlled environment. Of the 71 entries transplanted (including Jupiter and Bengal) from the field into the greenhouse, 23 entries showed a shift to S/MS from R/MR field rating.

The breeding-pathology tech support group provided an immeasurable amount of support to the success of research activities in extension pathology starting from preliminary to full-fledged applied research, collaborative research with industries and interdepartmental research such as the N-STaR by fungicide test along with evaluations of the breeding materials. Rice evaluations for diseases were also rendered for non-pathology faculty of the center upon request.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding pathology technical support program will always be to provide support to increase the efficiency of rice breeders in developing maximum yielding cultivars with high levels of disease resistance. A large number of entries scored resistant to moderately resistant for panicle blast. This helps demonstrate the breeding program is producing potentially useful advanced lines for Arkansas rice growers. Screening for leaf blast in the greenhouse and field identified a few entries having good resistance to the disease. Although the sheath blight nursery did not reveal any resistant lines, several moderately resistant/tolerant ones were identified. The other goal is to provide support to the rice extension plant pathology program with applied research to find the best answers for disease management. The rice extension pathology program largely focuses on BPB disease. Screening for BPB under field conditions identified over 60 entries (including entries duplicated in both tests) as having some level of resistance within the URRN/ARPT tests. Greenhouse testing is underway checking the consistency of disease responses of selected rice entries to BPB disease. Research on four cultural management options are now completed with the help of the tech support.

Because diseases are a major problem for crop production, a rigorous support group is vital to contend with major prevailing and newly emerging diseases. Every season is different with its established and newly progressing disease problems; therefore, extensive work in the rice disease area will always be important. A dedicated team of skilled individuals is required to assist the breeding and extension programs in attaining their goals of disease management options and disease resistance.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Arkansas rice producers and the support of the Arkansas Rice Research and Promotion Board through their continued interest and funding. Thanks also go to the USDA-ARS for their cooperation, interest, and evaluation of materials and to the other Division of Agriculture Research Stations located throughout Arkansas for their continued support.

LITERATURE CITED

Wamishe, Y., Y. Jia, T. Gebremariam, C. Kelsey, S. Belmar, and T. Mulaw. 2015. Characterization of rice germplasm for genetic resistance to bacterial panicle blight and development of techniques for monitoring the bacterial pathogen. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2014. University of Arkansas Agriculture Experiment Station Research Series 626:109-117. Fayetteville, Ark.

Table 1. Number of entries rated resistant or moderately resistant in 2014 field disease nurseries.

Test	Total entries	Sheath blight[a] MR/tolerant	Panicle blast[b,c] R	Panicle blast[b,c] MR	Leaf blast[b,d] R	Leaf blast[b,d] MR
ARPT	90	3	53	15	2	12
ARPT-IMI	33	0	13	7	0	0
URRN	197	3	90	54	3	40
Molden-CSIT	132	1	77	24	0	6
SIT-IMI	176	1	80	35	0	0
Sha-CSIT	245	0	141	70	0	6
Prelim	258	7	165	52	3	40
Hybrid	15	4	12	1	3	3
Aromatic	6	0	6	0	0	0
Missouri	100	5	39	23	0	0

[a] Sheath blight: Moderately resistant (MR)/tolerant entries had rating scores of 5 with no scores above 6.
[b] Five races were used in bulk for blast screening.
[c] Panicle blast: Resistant (R) entries with rating scores of 4 or less and up to two replications at 5. Moderately resistant entries had scores of 5 with no entries at or above 6.
[d] Leaf blast: Resistant entries with rating scores of 4 or less. Moderately resistant entries had scores of 5 with no entries at or above 6.

Table 2. Number of entries rated resistant or moderately resistant for 2014 greenhouse leaf-blast testing.

Test	Entry total	IB-1[a] R[b]	IB-1[a] MR[c]	IB-49 R[b]	IB-49 MR[c]	IC-17 R[b]	IC-17 MR[c]	IE-1K R[b]	IE-1K MR[c]
URRN	197	110	42	94	41	54	29	62	43
ARPT	92	50	15	43	29	64	17	24	12
Prelim	258	132	34	94	24	121	55	68	41
Sha CSIT	6	2	1	2	1	2	0	1	0
Hybrid	15	12	0	11	1	15	0	10	0
Advanced	4	2	2	1	1	1	2	0	2

[a] Data from blast races IB-1, IB-49, IC-17 and IE-1K used for table as these are most prominent.
[b] Resistant entries with ratings of 0 to 4 in 2 replications.
[c] Moderately resistant entries with ratings of 5 in 2 replications accompanied by 0 to 4 or 6 in last replication.

Table 3. Number of entries rated resistant (R) or moderately resistant (MR) for 2014 bacterial panicle blight testing.

Test	R or MR	Subset entries R or MR[a]
URRN	46	29
ARPT	49	29

[a] Entries were planted in both tests and received same ratings.

Breeding and Evaluation for Improved Rice Varieties—The Arkansas Rice Breeding and Development Program

*K.A.K. Moldenhauer, X, Sha, G.L. Berger, J. Hardke,
Y. Wamishe, C.E. Wilson Jr., R.J. Norman, M.M. Blocker,
D.K.A. Wisdom, D.L. McCarty, V.A. Boyett, B.A. Beaty, J.M. Bulloch,
D.L. Frizzell, C. Kelsey, S. Belmar, H. Sater, V. Booth, and V. Thompson*

ABSTRACT

The major goal of the Arkansas rice breeding program has been and will continue to be the development of new long- and medium-grain cultivars as well as specialty cultivars including aromatics and Japanese quality short-grains. Lines are evaluated and selected for desirable characteristics. Those with desirable qualities which require further improvement are utilized as parents in future crosses. Important components of this program include: high-yield potential, excellent milling yields, pest and disease resistance, improved plant type (i.e., short stature, semidwarf, earliness, erect leaves), and superior grain quality (i.e., low chalk, cooking, processing, and eating). New cultivars are continually being released to rice producers for the traditional southern U.S. markets as well as for the emerging specialty markets, which are gaining in popularity with rice consumers. This report entails a part of the overall rice breeding effort dealing with long-grain and specialty cultivar development in project ARK 2322 at the University of Arkansas.

INTRODUCTION

The rice breeding and genetics program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., is by nature a continuing project with the goal of producing improved rice cultivars for rice producers in Arkansas and the southern U.S. rice-growing region. The Arkansas rice breeding program is a dynamic team effort involving breeders, geneticists, molecular geneticists, pathologists, soil scientists, physiologists, entomologists, economists, systems agronomists, weed scientists, cereal chemists, extension specialists, and statisticians. We also encourage input from producers, millers, merchants and consumers. As breeders, we integrate information from all of these disciplines to make selections that are relevant to the needs of the entire rice industry. We are always looking for ways to enable the producer to become more economically viable, adding value to their product. Breeding objectives shift over time to accommodate the demands of these players.

Breeding objectives for improved long-grain and medium-grain cultivars include: standard cooking quality, excellent grain and milling yields, low chalk in the kernel, improved plant type, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal, more recently bacterial panicle blight has been added to this list. Blast resistance has been addressed by the pathology team, as well as through research by visiting scholars, and graduate students and by the development and release of the cultivars Katy, Kaybonnet, Drew, Ahrent, and Templeton. Banks was also a release from this program with blast resistance, but because blast resistance was derived from backcrossing, it did not contain the minor genes needed to protect it from *IE-1k* in the field. These cultivars are among the first to have resistance to all of the common southern U.S. rice blast races. These first blast-resistant cultivars released were susceptible to *IE-1k,* but they had field resistance, which kept the disease at bay. Templeton, the most recently released blast-resistant cultivar has resistance to the race *IE-1k*. Furthermore, many of the experimental lines in the Arkansas rice breeding program have the gene *Pi-ta* which provides resistance to most southern blast ecotypes and some of these also have resistance to *IE-1K*. Sheath blight tolerance also has been an ongoing concern and the cultivars from this program also have had the best sheath blight tolerance of any in the U.S. Rough-rice grain yield has become one of the most important characteristics in the last few years and significant yield increases have been realized with the release of the long-grain cultivars LaGrue, Wells, Francis, Banks, Taggart, Roy J, and LaKast.

PROCEDURES

The rice breeding program continues to utilize the best available parental material from the U.S. breeding programs, the USDA World Collection, and the International Center for Tropical Agriculture (CIAT), the International Rice Research Institute (IRRI), and the West Africa Rice Development Association (WARDA). Crosses are made yearly to improve grain yield and to incorporate genes for broad-based disease resistance, improved plant type (i.e., short-stature, earliness, erect leaves), superior quality (i.e., low chalk, cooking, processing, and eating), and N-fertilizer use efficiency into highly productive well-adapted lines. The winter nursery in Puerto Rico is utilized to accelerate head row and breeders seed increases of promising lines, and to advance early generation selections each year. As outstanding lines are selected and advanced, they are evaluated extensively for yield, milling, chalk, cooking characteristics, insect tolerance (entomology group), and disease resistance (pathology group). Advanced lines are evaluated for N-fertilization recommendations, which include the proper timing and rate of N-fertilizer (soil fertility group), and for weed control practices (weed scientists).

The rice breeding program utilizes all feasible breeding techniques and methods including hybridization, backcrossing, marker-assisted selection, mutation breeding, and other biotechnology to produce breeding material and new cultivars. Segregating populations and advanced lines are evaluated for grain and milling yields, quality traits, maturity, plant height and type, disease and insect resistance, and in some cases cold tolerance. The statewide rice performance testing program, which includes rice varieties and promising new lines developed in the Arkansas program and from cooperating programs in the other rice-producing states, is conducted each year by the Rice Extension Specialist. These trials contribute to the selection of the best materials for future release and provide producers with current information on rice variety performance. Disease data are collected from ongoing inoculated disease plots (which are inoculated with sheath blight, blast and bacterial panicle blight), from general observation tests planted in fields with historically high incidences of disease, and from general observations made during the agronomic testing of entries.

RESULTS AND DISCUSSION

LaKast, which was released to seed growers in 2014, is a high yielding, very-short-season, long-grain line. LaKast originated from the cross, no. 20001653, which has LaGrue, Katy, and Starbonnet in its parentage. It had excellent yields during the hot growing season of 2010, 194 bu/acre compared to Francis and Roy J at 184 and 179 bu/acre, respectively. The yield of LaKast for the 2012-2014 Arkansas Rice Performance Trials (ARPT) was 192 bu/acre compared to Roy J, Wells, and Mermentau at 200, 185, and 180 bu/acre, respectively (Table 1). Its benefit over Roy J is that it reaches maturity five to seven days earlier. LaKast will be available as registered seed in 2015. LaKast has one of the longest kernels at over 7 mm. Head rice yield and cooking quality are also comparable to Wells and it has a clear translucent kernel with low chalk (Table 1). LaKast and Wells both have moderate lodging resistance ratings. The milling yield of LaKast in the ARPT, 2012-2014 (Table 1) was 62% head rice and 71% total rice. The total season nitrogen application recommendations for LaKast are 150 lb/acre. LaKast does not carry any major resistance genes and is therefore susceptible to rice blast, similar to Roy J or Wells. It is also susceptible to bacterial panicle blight as well as kernel smut like Wells. LaKast is considered moderately susceptible to straighthead and is comparable with Catahoula or CL142-AR.

This program has also released a promising Clearfield cultivar, CL172, to BASF for increase. This line has Drew, CL161, Katy, Starbonnet, a Drew sister line, Lemont, radiated Bonnet 73, and a Francis sister line in its pedigree. CL172 was included in the Uniform Regional Rice Nursery (URRN) and ARPT for the first time in 2012 and now has three years of field data illustrating its superior lodging resistance and high yield potential relative to other modern Clearfield cultivars. In the ARPT in 2012-2014 (Table

1), it yielded 184 bu/acre compared to CL151, CL152, CLXL729, and CLXL745 at 184, 158, 188, and 181 bu/acre, respectively. Clearfield 172 is comparable with CL151 and CL152 in that it has semidwarf plant stature. It is also short seasoned, and carries the gene *Pi-ta* which provides resistance to the common blast races in the southern growing region. It maintains excellent grain quality with clear translucent kernels that have very little chalk present. The total season nitrogen application recommendation for CL172 is 135 lb/acre. Additional data will be collected on this line in the ARPT, URRN, and DD50 in 2015. Seed of CL172 will have limited availability in 2016 through Horizon Ag.

A promising experimental line that displayed excellent cultivar potential in the 2013 and 2014 ARPT was 131084. This line originated from a cross between a Francis anther culture line and Roy J. It has an exceptionally high yield with an average overall yield of 205 bu/acre in two-year average for the ARPT compared to Roy J, LaKast, and RTXL753 at 190, 189, and 233 bu/acre, respectively (Table 2). This line is short seasoned with low susceptibility to lodging and high milling yield potential. It will continue to be examined the 2015 ARPT and URRN and grown as a foundation seed field in 2015.

Crosses have been made for high yield, good quality, improved milling, and disease resistance in various combinations. Crosses were made for both long- and medium-grain conventional and Clearfield in 2014. The F_2 populations from these crosses will be evaluated in 2015 and selections will be grown in the winter nursery during the winter of 2015-2016. Currently, we have 4000 F_3 lines growing in Puerto Rico. One or two panicles will be harvested to produce F_4 lines grown at the RREC as P panicle rows in 2015.

Marker-assisted selection continues to be utilized by this program to help select improved lines with specific genes. In this program, molecular markers allow selection of lines which carry genes associated with high yield in the wild species *Orzya rufipogon*, the *Pi-ta* gene for blast resistance, and the CT classes to predict cooking quality (see Boyett et al., 2005 and 2009). In 2014 there are 2 lines from the *Oryza rufipogon* crosses in the ARPT. Additionally, this program is conducting research that aims to identify molecular markers linked to quality traits. These markers will enable breeders to select for high milling quality in early breeding generations. The data derived from this project improves our accuracy and efficiency in choosing parents and advancing lines.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum yielding cultivars with excellent quality and good levels of disease resistance for release to Arkansas rice producers. The release of Taggart, Templeton, and Roy J and most recently LaKast and CL172 demonstrate that continued improvements in rice cultivars for the producers of Arkansas are achieved through this program. LaKast could potentially be the modern replacement for Wells. Improved lines will continue to be released from this program in the future. New cultivars will have the characteristics of improved disease resistance, plant type, rough rice grain and milling yields, low chalk, the desired larger kernel size, and overall grain quality. In the future, new rice varieties will be released not only for the traditional southern U.S. long- and medium-grain markets but also for specialty markets that have emerged in recent years

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Arkansas rice producers, and the support of the Arkansas Rice Research and Promotion Board through their continued interest and funding. Thanks also go to the USDA-ARS for their cooperation, interest and evaluation of materials, and to the other Division of Agriculture Research Stations located throughout Arkansas for their continued support.

LITERATURE CITED

Boyett, V.A., J.W. Gibbons, J.Jiang, and K.A.K. Moldenhauer. 2005. Advancements in marker-assisted selection methods and applications. *In:* R.J. Norman, J.F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2004. University of Arkansas Agricultural Experiment Station Research Series 529:25-29. Fayetteville, Ark.

Boyett, V.A., J. You, and K.A.K. Moldenhauer. 2009. Challenges of marker-assisted selection of quantitative trait loci introgression form *O. rufipogon*. *In:* R.J. Norman, J.F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:56-61.

Table 1. Three year average 2012-2014 Arkansas Rice Performance Trials for LaKast, CL172 and other cultivars.

Cultivar	Grain type[a]	Yield[b] 2012	2013	2014	Mean	Height	50% Heading	Chalky kernels[c]	Milling[d]
		(bu/acre)				(in.)	(days)		(HR:TOT)
LaKast	L	196	186	193	192	42	83	0.82	62:71
Wells	L	194	178	182	185	41	85	0.95	58:70
Mermentau	L	199	173	168	180	37	83	1.55	65:70
Taggart	L	187	186	187	187	44	87	0.70	59:70
Roy J	L	219	188	192	200	41	88	0.68	62:70
RTXL753[e]	L	229	225	246	233	42	81	1.67	57:71
RTCLXL745[f]	L	185	165	193	181	43	80	1.15	60:70
RTCLXL729	L	184	188	191	188	43	83	2.22	61:71
CL172	L	214	174	165	184	35	84	0.70	64:71
CL151	L	191	169	190	184	39	83	1.46	64:71
CL152	L	179	153	144	158	37	85	1.11	65:71

[a] Grain type L = long-grain.

[b] Yield trials in 2012 consisted of five locations, Rice Research and Extension Center (RREC), near Stuttgart, Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Newport Extension Center (NEC), Newport, Ark.; and Clay County Farmer Field (CC), Corning, Ark.; in 2013 trials were at CC, Desha County Farmer Field (DC), NEREC, NEC, PTRS, and RREC.; and in 2014 the trials were conducted at RREC, PTRS, NEREC, CC, and DC.

[c] Data for chalk is from 2011-2012 Riceland Grain Quality Laboratory data.

[d] Milling figures are head rice : total milled rice 2012-2014.

[e] RT stands for RiceTec.

[f] CL stands for Clearfield lines.

Table 2. Data from the 2013-2014 Arkansas Rice Performance Trials for a promising long-grain experimental line and check cultivars.

	Yield[b]								
Cultivar[a]	CC	DC	NEREC[d]	PTRS	RREC	Mean	Height	Heading	50% Milling[c]
	(bu/acre)						(in.)	(days)	(HR:TOT)
EXP131084	195	214	209	187	220	205	41	84	62:69
LaKast	184	199	176	185	195	189	41	83	63:71
Roy J	195	194	191	177	195	190	42	88	63:71
Wells	189	186	165	166	185	180	42	85	60:70
RTXL753	242	241	226	229	228	233	42	81	59:71

[a] RT stands for RiceTec, EXP for experimental lines not for sale.

[b] Yield trials in 2013 consisted of five locations, Rice Research and Extension Center (RREC), near Stuttgart Ark.; Pine Tree Research Station (PTRS), near Colt, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Clay County Farmer Field (CC), Corning, Ark.; and Desha County Farmer Field (DC); and in 2014 the locations were RREC, PTRS, CC, and DC.

[c] Milling figures are head rice : total milled rice.

[d] Data for NEREC only from 2013.

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South

X. Sha, K.A.K. Moldenhauer, B.A. Beaty, J.M. Bulloch, D.K.A. Wisdom, M.M. Blocker, D.L. McCarty, V.A. Boyett, J.T. Hardke, and C.E. Wilson Jr.

ABSTRACT

To reflect the recent changes of the state rice industry and streamline the delivery of new and improved rice varieties to the Arkansas rice growers, the new medium-grain rice breeding project will expand its research areas and breeding populations to include both conventional and Clearfield medium- and semi-dwarf long-grain rice, as well as hybrid rice. Newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins will be actively collected, evaluated, and incorporated into the current crossing blocks for the programmed hybridization. To improve the efficiency and effectiveness, maximum mechanized-operation, multiple generations of winter nursery, and new technologies such as molecular marker-assisted selection (MAS) will also be rigorously pursued.

INTRODUCTION

Medium-grain rice is the important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2004-2013, an average of 0.15 million acres of medium-grain rice was grown annually, which makes up about 10% of total state rice acreage (USDA-ERS, 2014). Planted acres of medium-grain rice in Arkansas in the last decade have varied from a high of 243,000 acres in 2011 (21% of total rice planted in Arkansas) to a low of 99,000 acres in 2008 (7% of total rice planted in Arkansas).

A significant portion of Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CL111, CL151, CL152, and Mermentau. However, locally developed semi-dwarf varieties offer advantages including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines also can be directly adopted by the newly established hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts should and will continue.

The inter-subspecies hybrids between *indica* male sterile lines and tropical *japonica* restorer/pollinator lines that were first commercialized in the United States in 1999 by RiceTec have a great yield advantage over conventional pure-line varieties (Walton, 2003). However the further expansion of hybrid rice may be constrained by its inconsistent milling yield, poor grain quality, lodging susceptibility, seed shattering, and high seed cost. A public hybrid-rice research program that focuses on the development of adapted lines (male sterile, maintainer, and restorer lines) will be instrumental to overcome such constraints.

PROCEDURES

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection will be carried out on backcross or top-cross progenies on simply inherited traits such as blast resistance and physicochemical characteristics. Segregating populations are planted, selected, and advanced at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and the winter nursery in Lajas, Puerto Rico. The pedigree and modified single seed descent will be the primary selection technology employed. A great number of traits will be considered during this stage of selection including grain quality (shape and appearance), plant type, short stature, lodging resistance, disease (blast, sheath blight, and panicle blight) resistance, earliness, and seedling vigor. Promising lines having a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Milling small samples, as well as the physicochemical analysis at the USDA Rice Quality Lab at Dale Bumpers National Rice Research Center near Stuttgart, Ark., and at Riceland Foods, Inc. Research and Technology Center, Stuttgart, Ark., will be conducted to eliminate lines with evident quality problems and to maintain standard U.S. rice quality for the different grain types. Yield evaluations include the Stuttgart Initial Yield Trial (SIT) and Clearfield SIT (CSIT) at the RREC; the Advanced Yield Trial (AYT) at the RREC; the Pine Tree Research Station (PTRS) near Colt, Ark.; and the Northeast Research and Extension Center (NEREC) Keiser, Ark.; the Arkansas Rice Performance Trials (ARPT) conducted by Jarrod Hardke, rice extension specialist, at six locations in rice-growing regions across the state; and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in Louisiana, Mississippi, Missouri, and Texas. Promising advanced lines will be provided to cooperating projects for the further evaluation of resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT or CSIT and beyond will be planted as headrows for purification and increase purposes.

RESULTS AND DISCUSSION

During the transition of this project, a number of breeding populations of different stages were maintained by Karen Moldenhauer. Selection and advancement of those materials was continued in 2014. A great number of new populations were created and rapidly advanced, which included 440 transplanted F_1 populations, 648 space-planted F_2 populations, and 47,800 panicle rows ranging from F_3 to F_6. A total of 353 transplanted F_1 populations were selected and bulk-harvested for planting of F_2 populations in 2015. Visual selection on approximately 600,000 individual space-planted F_2 plants resulted in a total of 30,000 panicles, which will be grown as F_3 panicle rows in 2015. From 47,800 panicle rows, 3394 were selected for advancement to the next generation, while 1173 rows appeared to be uniform and superior to others, therefore were bulk-harvested as candidates of 2015 SIT or CSIT trials. In 2014, a Clearfield (CL) preliminary yield trial (CSIT) was carried out at both RREC and PTRS, evaluating 247 breeding lines which included 225 semi-dwarf CL long-grain and 22 CL medium-grain lines. Three hundred three semi-dwarf breeding lines that consisted of 200 long-grain and 103 medium-grain lines were tested in the SIT trial conducted at both RREC and Rohwer Research Station near Watson, Ark. A number of breeding lines showed the yield potential similar to or better than the check varieties (Tables 1–4). Sixteen advanced breeding lines were evaluated in the ARPT and multi-state URRN trials. Results of those entries and selected check varieties are listed in Table 5. Three Puerto Rico winter nurseries of 10,500 rows were planted, selected, harvested and/or advanced throughout 2014. Four hundred new crosses were made in 2 weeks in the summer of 2014, which included 125 CL long-grain, 23 CL medium-grain, 99 semi-dwarf conventional long-grain, and 153 conventional medium-grain crosses.

The conventional medium-grain line 13AR1021 (RU1301021) continued showing excellent yield potential, good milling, and superior grain quality in trials across Arkansas and the mid-South in 2014. Breeder headrows of 13AR1021 were planted and harvested in 2014 and the foundation seed will be grown in 2015 for varietal release purposes. The conventional semi-dwarf long-grain line 14AR1136 (RU1401136) and CL semi-dwarf long-grain line 14AR1044 (RU1401044) were selected for purification and increase in 2015 for their superior yielding potential, good disease resistance, and excellent milling and grain quality. A total of 110 semi-dwarf and early-maturing conventional medium- and long-grain lines, as well as Clearfield lines that possess great yield potential, good milling and grain quality were also identified from CSIT and SIT trials, and will be further evaluated in the laboratory before entering URRN, ARPT, and AYT test in 2015.

SIGNIFICANCE OF FINDINGS

Successful development of medium-grain and semi-dwarf long-grain rice varieties offer producers options in their choice of variety and management systems for Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

ACKNOWLEDGMENTS

This research is partially funded by monies administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

USDA-ERS. 2014. United States Division of Agriculture-Economic Research Service. 2014 Rice Yearbook. Available online at http://www.ers.usda.gov/data-products/rice-yearbook-2014.aspx.

Walton, M. 2003. Hybrid rice for mechanized agriculture. pp. 97-102. *In:* S.S. Virmani, C.X. Mao, and B. Hardy (eds.). Hybrid Rice for Food Security, Poverty Alleviation, and Environmental Protection. International Rice Research Institute, Los Baños, Philippines.

Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2014.

Variety/line	Pedigree	Seedling vigor[a]	50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
			(days)	(cm)	(bu/acre)	------------- (%)	---------
14CSIT304	CL111//CCDR/0502085	3.5	89	101	265	67.5	71.9
14CSIT311	CL111/3/CCDR//9502008/LGRU	4.0	92	103	262	70.2	73.6
14CSIT262	TACAURI/3/CPRS//82CAY21/TBNT/4/CFX18/5/CHNR	3.5	92	109	260	69.7	72.4
14CSIT302	CL111/CCDR	4.0	89	105	256	67.4	71.9
14CSIT305	CL111//CCDR/0502085	4.0	91	100	255	67.2	71.3
14CSIT297	CPRS/KBNT//CFX29/CCDR/3/06CFP952	4.0	94	105	254	67.4	70.8
14CSIT247	CPRS/KBNT//WLLS/CFX18/3/CHNR	4.0	93	108	252	69.7	73.8
14CSIT390	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	3.5	92	102	252	70.7	74.5
14CSIT344	RU0902125/CL131	3.5	94	102	251	69.8	73.3
14CSIT227	CHNR/4/CPRS/9502008-A/3/CFX 29//AR1142/LA2031	4.0	98	110	251	70.3	73.4
14CSIT395	KATY/CPRS//JKSN/3/AR1188/CCDR/4/CFX-29/CCDR	4.0	91	104	251	71.8	75.9
CL111	CL111	3.0	91	110	227	70.8	74.2
CL151	CL151	3.5	92	106	272	70.6	74.2
CL152	CL152	4.0	97	105	202	69.8	72.5
CL172	CL172	3.5	96	95	235	70.1	73.3

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2014.

Variety/line	Pedigree	Seedling vigor[a]	50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
			(days)	(cm)	(bu/acre)	------------- (%)	---------
14CSIT316[b]	BNGL/CL161/4/9502065/3/MERC//MERC/…	4.0	91	102	267	69.0	70.4
14CSIT307[b]	NPTN//BNGL/CL161	3.5	93	105	258	69.9	71.2
14CSIT315[b]	BNGL/CL161/4/9502065/3/MERC//MERC/…	4.0	91	105	257	70.8	72.0
14CSIT314[b]	BNGL/CL161/4/9502065/3/MERC//MERC/…	3.0	93	115	255	70.3	71.6
14CSIT308[b]	NPTN//BNGL/CL161	4.0	94	102	254	70.1	71.4
14CSIT447[c]	STG07IMI-01-129/JPTR	4.0	79	103	250	63.7	69.8
14CSIT452[c]	CL181/JPTR	3.5	75	110	242	59.4	70.4
CL111[b]	CL111	3.0	94	105	229	70.2	73.4
CL151[b]	CL151	3.0	90	105	278	70.3	73.4
CL152[b]	CL152	4.0	99	102	208	69.2	72.5
CL172[b]	CL172	4.0	97	96	233	68.5	71.8
CL271[b]	CL271	4.0	93	106	252	71.3	72.9
CL271[c]	CL271	3.0	83	107	210	63.4	71.2

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 11 April 2014.
[c] Planted on 12 May 2014.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2014.

Variety/line	Pedigree	Seedling vigor[a]	50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
			(days)	(cm)	(bu/acre)	------------- (%)	---------
14SIT837[b]	JPTR/RU1001102	4.0	90	99	266	67.0	69.3
14SIT895[c]	RU0801173/JPTR	3.0	75	107	254	56.0	66.9
14SIT904[c]	STG03AC-21-047/RU0902162	3.0	77	102	250	54.2	70.7
14SIT899[c]	RU0801173/JPTR	3.5	75	107	248	34.9	67.6
14SIT892[c]	RU0801173/STG07M-07-096	3.5	72	108	247	51.5	67.1
14SIT881[c]	RU0602071/RU0402146	4.0	77	103	247	43.2	68.3
14SIT804[b]	M207/JPTR//JPTR	4.0	95	109	246	67.4	68.6
14SIT873[c]	EARL/4/9502065/3/BNGL//MERC/RICO	3.5	76	104	246	58.1	68.6
14SIT891[c]	RU0902162/RU0801124	3.5	78	106	245	56.5	68.5
14SIT898[c]	RU0801173/JPTR	3.0	76	102	245	54.2	67.9
14SIT838[b]	JPTR/RU1001102	4.0	92	90	244	67.7	69.7
14SIT863[c]	BNGL/SRICO/4/9502065/3/BNGL//MERC/RICO	4.0	76	103	241	52.8	64.5
14SIT835[b]	CFFY/STG07M-07-096	4.5	90	105	241	69.4	70.9
Jupiter[b]	Jupiter	3.5	93	95.5	258	68.4	70.1
Caffey[b]	Caffey	3.5	94	98.5	253	70.6	71.8
Caffey[c]	Caffey	3.0	82	106	216	50.2	68.1

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 11 April 2014.
[c] Planted on 12 May 2014.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the Rice Research and Extension Center near Stuttgart, Ark., 2014.

Variety/line	Pedigree	Seedling vigor[a]	50% heading	Plant height	Yield	Milling yields Head rice	Milling yields Total rice
			(days)	(cm)	(bu/acre)	------------- (%)	---------
14SIT623	CPRS/KBNT//9502008-A	3.0	92	98	259	70.5	73.9
14SIT712	MRMT/4/9502008//AR1188/CCDR/3/CCDR	4.0	90	98	257	69.1	72.8
14SIT624	CYBT/LM1//CHNR/3/ADAR/JDON//JEFF	4.5	90	104	257	66.3	72.5
14SIT664	CYBT/LM1/4/WLLS/PI597049/3/RSMT//NWBT/KATY...	4.0	91	108	255	69.3	72.8
14SIT753	CCDR//CCDR/JEFF/3/CCDR	4.0	94	97	252	70.2	74.9
14SIT758	0402022/3/9502008//AR1142/MBLE/4/CTHL	4.0	94	105	252	71.5	74.9
14SIT744	RU1002125/FRNS	3.5	90	115	251	70.6	74.4
14SIT622	CYBT/LM1//CHNR/3/ADAR/JDON//JEFF	4.0	93	105	250	68.9	73.1
14SIT717	RU0902174/RU0902134	3.5	94	100	249	70.2	73.4
14SIT679	CCDR/RU0801167	4.0	90	107	248	70.2	73.8
CL111	CL111	3.0	90	103	245	70.4	74.0
CL151	CL151	3.0	90	99	273	69.7	73.6
LaKast	LaKast	3.0	92	111	255	68.7	73.0
Mermentau	Mermentau	3.5	95	99	211	70.4	73.5
Wells	Wells	3.0	92	112	242	69.7	74.3

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

Table 5. Average yield, milling, and agronomic characteristics of selected experimental long-grain and medium-grain lines and check varieties in the Arkansas Rice Performance Trials at five Arkansas locations, 2014.

Entry	RU	Pedigree	Grain type	50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(days)	(cm)	(bu/acre)	------------- (%)	---------
14ARPT269	RU1301021	M206//BNGL/LFTE/3/JPTR	M	83	98	206	55	69
14ARPT274	RU1301130	M206/STG03AC-21-047//JPTR	M	89	106	170	64	70
14ARPT275	RU1401130	CFFY/STG07M-07-096	M	86	100	172	62	68
14ARPT266	RU1401044	RU0902125/CL131	CL	87	92	150	63	70
14ARPT267	RU1401121	CCDR//CCDR/JEFF/3/CL131	CL	87	92	151	66	71
14ARPT270	RU1401133	RU0902125/CL131	CL	89	95	150	63	69
14ARPT276	RU1401127	CYBT/LM1//CHNR/3/ADAR/JDON//JEFF	L	86	97	162	65	70
14ARPT277	RU1401136	CYBT/LM1/4/WLLS/PI597049/3/RSMT//…	L	88	90	168	55	67
14ARPT208	Jupiter	Jupiter	M	87	96	177	59	69
14ARPT209	Caffey	Caffey	M	87	97	189	57	69
14ARPT217	CL111	CL111	CL	85	95	148	63	71
14ARPT211	CL151	CL151	CL	86	96	170	65	71
14ARPT212	CL152	CL152	CL	88	92	139	65	71
14ARPT224	CL172	CL172	CL	87	88	156	66	71
14ARPT202	Roy J	Roy J	L	90	105	171	62	70
14ARPT207	Mermentau	Mermentau	L	86	95	159	66	71

Development of Aromatic Rice Varieties

*D.K.A. Wisdom, K.A.K. Moldenhauer, C.E. Wilson Jr.,
X. Sha, J.M. Bulloch, B.A. Beaty, M.M. Blocker, and V.A. Boyett*

ABSTRACT

Interest in aromatic rice has increased. The advent of nouveau cuisine has caused a rise in niche markets. Sales of aromatic rice have led rice imports to increase by 31% in the last seven years. The University of Arkansas System Division of Agriculture's Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), near Stuttgart, Ark., was implemented to develop aromatic rice varieties for the southern rice-producing regions. Lines which do not have photoperiod sensitivity have been selected for yield evaluation in the Arkansas Rice Performance Trials (ARPT) and the Uniform Regional Rice Nursery (URRN).

INTRODUCTION

Approximately 13.6 MM cwt of milled rice were imported to the United States in the fiscal year 2011/2012, an increase of 31% in the last seven years (USA Rice Federation, 2009, 2012). The top supplying countries are Thailand, which produces high quality Jasmine rice, and India, which produces highly desired Basmati rice (USA Rice Federation, 2012). United States consumers are purchasing more aromatic and/or specialty rices than in previous years. It has been difficult for U.S. producers to grow the true Jasmine and Basmati varieties due to environmental differences, photoperiod sensitivity, fertilizer sensitivity, and low yields. These difficulties make aromatic rice an expensive commodity to produce. Adapted aromatic rice varieties need to be developed for Arkansas producers which meet the taste requirements for Jasmine and/or Basmati.

PROCEDURES

The aromatic rice breeding program collected parental material from the U.S. breeding programs and the USDA World Collection. Crosses were made to incorporate traits for aroma, yield, improved plant type, superior quality, and broad-based disease resistance. The winter nursery in Puerto Rico is being employed to accelerate generation advance of potential varieties for testing in Arkansas during the summer of 2015.

RESULTS AND DISCUSSION

In 2014, 47 cross-pollinations were made to produce aromatic lines for screening. The F_1 plants from these crosses will be grown in the greenhouse during the winter to produce F_2 seed. The F_2 populations will be planted in 2015 at RREC for observation and selection.

Panicles were selected from 31 F_2 populations in 2014. The parents in these crosses were selected for their aromatic seed quality or high yield potential. Approximately 250 F_3 lines from eight populations were shipped to the winter nursery in Puerto Rico to advance. The harvested seed from Puerto Rico will be planted at RREC for further observation and selections in 2015. Panicle rows from 32 F_4 and F_5 populations will be grown in 2015 for selections. Marker analysis will be conducted to detect or determine the characteristics of aroma, cooking quality, and blast resistance.

In 2014, 47 heterozygous lines from 14 F_3 and F_4 populations were screened through marker-assisted selection for aroma and amylose content. Results of the screening helped to eliminate lines which did not meet breeding program requirements. The entries which are homozygous aromatic and have *Pi-ta*, *Pi-b*, or *Pi-k* blast resistance will move forward into yield trials.

Two preliminary yield trials were planted in 2014. A two-replication trial included 38 aromatic lines and a one-replication test included 37 aromatic lines. The 11 highest yielding lines were screened for aromatic flavor by conducting a taste test. The six experimental lines chosen as having the best flavor and aroma have been entered in the ARPT and are being grown in increase plots in 2015. Four aromatic experimental lines have been entered in the 2015 URRN.

In 2014, six experimental lines were entered in the ARPT and three experimental lines were entered in the URRN. One experimental line that showed promising potential in the ARPT and URRN was EXP141105. This line originated from a cross between Jazzman and a plant introduction line. EXP141105 has excellent flavor and will continue to be examined in the ARPT and URRN in 2015.

ACKNOWLEDGMENTS

The authors appreciate the financial support of the rice producers of Arkansas through monies administered by the Arkansas Rice Research and Promotion Board. We thank Veronica Booth and Vetress Thompson for conducting marker analysis.

LITERATURE CITED

USA Rice Federation. 2009. "U.S. Rice Domestic Usage Report For the Milling Year August 1, 2008 - July 31, 2009." www.USARice.com. Accessed January, 2014.

USA Rice Federation. 2012. "U.S. Rice Domestic Usage Report For the Milling Year August 1, 2011 - July 31, 2012." " www.USARice.com. Accessed January, 2014.

Seed Management to Control Bacterial Panicle Blight of Rice

S.B. Belmar, C.D. Kelsey, T.A. Gebremariam, and Y.A. Wamishe

ABSTRACT

Burkholderia glumae was frequently isolated from symptomatic panicles and seeds that had bacterial panicle blight (BPB) disease. Different seed management methods were tested anticipating a short-term disease control strategy of planting cleaner seed to prevent the introduction of bacteria to a field. After separating seeds into two weight classes as "sinkers" and "floaters," *B. glumae* was recovered from both fully and partially developed rice seed. Therefore, the short-term disease control strategy of planting plump healthy-looking seeds to limit spread of BPB appeared unlikely. Although several industrial chemicals showed encouraging results toward reducing recovery of bacteria on media plates, they also reduced seed germination. Use of natural aqueous plant extracts made from fringed rue, garlic, ginger, kudzu, Palmer's pigweed, and rosemary lacked consistency in controlling *B. glumae*. Application of UV light, microwave, or freezing temperatures did not lower the survivorship of *B. glumae*. Vinegar at 2% controlled the most bacteria without greatly lowering the seed germination. Dry heat of 55 °C applied for 72 h also maximized the kill of bacteria without lowering seed germination. Artificially inoculated Bengal seeds treated with 2% vinegar and 55 °C dry heat planted in a field showed substantial reduction in BPB disease in 2013 compared to the untreated control. When repeated in 2014, the results were consistent but not as sizable as the prior year. More research is needed to understand the etiology and epidemiology of bacterial panicle blight for development of reliable seed management options. This study on possible seed dressing options to manage rice bacterial panicle blight disease is encouraging and more active leads will be investigated in the future.

INTRODUCTION

Bacterial panicle blight (BPB) is a weather dependent and sporadic disease that remains an ongoing priority in Arkansas because of serious yield losses incurred in recent years. The disease is caused by the gram-negative bacterium, *Burkholderia glumae* (Nandakumar et al., 2009). Much remains unknown on the etiology and environmental factors. A laboratory culture of seeds collected from symptomatic field-grown panicles in Arkansas yielded bacteria that turned culture media a bright yellow on CCNT, a partially selective medium for *B. glumae*. Current fungicides used on rice in the U.S. have no activity in controlling this disease. Therefore, research was undertaken in the past three years to evaluate common household and industrial chemicals, natural plant extracts, and various physical conditions in an attempt to manage bacterial panicle blight using seed.

PROCEDURES

Managing Seeds for Planting Through Seed Cleaning to Reduce or Eliminate Bacterial Panicle Blight

Anticipating that the healthy-looking and plump seeds collected from naturally infected seed lots could be free of *B. glumae*, a preliminary test was undertaken in the off season of 2011. Seeds from Clearfield (CL) 111, CL142-AR, CL151, CL152, CL162, and CL181-AR were obtained from Horizon Ag harvested in 2011 from plots planted near Carlisle; Ark. Test plots selected for this study had considerable amounts of BPB disease, with the worst being on CL181AR. Ammonium sulfate fertilizer was used for density separation of the seed components. Ammonium sulfate (30 g/100 mL water) was standardized to separate 40 g of seed into two classes as "floaters" and "sinkers". The floaters composed of light weight seeds, chaff, and rice residue and the sinkers included only the plump healthy-looking seeds. A grinding buffer was prepared [41 g of sodium acetate/1 L distilled water was made and brought to pH 5 before adding 0.85% sodium chloride (Ron Saylor, pers. comm.)]. Twenty seeds of each class and variety were ground separately in sterile mortar and pestle with 1-mL extraction buffer or water to obtain a seed extract. Approximately 24 drops were spotted over a petri plate containing CCNT medium (Kawaradani et al., 2000), a semi-selective media for *B. glumae*. Then plates were incubated at 39 °C from 3 to 5 days. Yellow pigment in the agar around each spot was considered positive for the presence of *B. glumae*. To test for germination, 100 kernels from each class and variety were put on moist filter paper (Qualitative 415, VWR International, Radnor, Pa.) and allowed to germinate in the dark at room temperature for approximately one week.

Tests for Seed Dressing Treatments Against Bacterial Panicle Blight Rice Disease

Testing started with naturally infected seeds. Due to erratic results, seeds were artificially inoculated to obtain uniform seeds carrying the *B. glumae* bacteria. Seeds were inoculated either by immersion in bacterial suspension or using vacuum infiltration. Approximately 80 g of rice seeds were submerged by washing a 24 to 48 h old culture of *B. glumae* grown on King's B media plates. A light milky suspension [~10^7 to 10^8 cfu/mL (colony forming unit/mL)] was used. Seeds in bacterial suspension were allowed to shake (C-10 platform shaker, New Brunswick Scientific, Edison, N.J.) at 160 rpm for 24 h in a 150-mL flask. After the incubation period, excess bacterial suspension was drained off and seeds were immediately ready for wet seed chemical treatments. For the dry seed treatment, the *B. glumae* culture on King's B media plates were washed from a petri dish with sterile water to obtain a 1-mL suspension of approximately 10^6 to 10^9 cfu/mL. The bacterial suspension was mixed with 4-mL salt-sugar buffer having 1 g yeast extract, 2.4 g NaCl, 3.4 g sucrose per liter of distilled water (Streeter, 2007). The salt-sugar buffer was used to aid in survivorship of the bacteria through the desiccation process. The mixture was infiltrated into 40 g of rice seed by applying a vacuum (25 inch Hg) for 5 min in a loosely sealed mason jar followed by restoring atmospheric pressure with the removal of the lid. The vacuuming process was repeated a second time. For handling convenience, seed treatments were broadly classified as "industrial", "household", "natural plant extracts", and "physical/non-chemical".

Industrial Products to Control B. glumae. Industrial chemicals included a proprietary silver-based compound, streptomycin sulfate (Sigma Chemical Co., St. Louis, Mo.), Kocide 2000 and Mankocide (E.I. du Pont de Nemours and Co., Wilmington, Del.), and oxolinic acid (S/M/C Inc., Fla.). Wet seeds and dry seeds were treated with the chemicals. Twenty grams of seeds were put into separate jars. An aqueous dissolved aliquot of chemical was added to each. Jars were sealed and shaken for 10 min, then left at room temperature for various times (2 to 24 h) to allow diffusion of the chemical products into the seed. Chemically treated seeds were immediately plated on CCNT media to establish control plates. The remaining seed was then plated following the treatment duration. Plates were incubated for at least 2 days at 39 °C and as soon as the control plates showed signs of light yellow, then number of positive seed was recorded for the entire test.

Household Chemicals to Control B. glumae. To treat "dry" inoculated seeds, 20 g were put into separate jars. Aliquots of the chemical products Clorox (The Clorox Co., Oakland, Calif.), 2% vinegar (H.J. Heinz Co., Pittsburgh, Pa.), Cecure® CPC (cetylpyridinium chloride) antimicrobial (Safe Foods Corp, North Little Rock, Ark.), hydrogen peroxide and isopropyl alcohol (Aaron Industries, Clinton, S.C.) were carefully dispersed over the seed and then jars were sealed and shaken for 10 min. Selected chemical treatments such as Clorox were also vacuum infiltrated twice at 5 min apiece (25 inches Hg) in an effort to distribute the chemical treatment within the seed. Seeds were allowed to air dry for 1 h before plated on CCNT media and incubated for up to three days at 39 °C. The number of seeds showing a yellow pigment was recorded as positive for *B. glumae*. Additional household products including ammonia, mouthwash (Equate, Bentonville, Ark.), toothpaste (Colgate-Palmolive Co., New York, N.Y.), and toilet bowl cleaner (Reckitt Benckiser LLC, Parsippany, N.J.) were also evaluated using dry inoculated seeds. Approximately 20 g of inoculated seed was placed in a liquid seed dresser (model Hege 11, Wintersteiger, Inc., Salt Lake City, Utah) for application of household products. Chemically treated seeds were allowed to air dry and were plated on CCNT media. Plates were incubated for up to three days at 39 °C before counting positive seeds for *B. glumae*.

Evaluating Plant Extracts to Control Rice Bacterial Panicle Blight. Aqueous plant extracts were freshly made from rosemary (*Rosmarinus officinalis*), Palmer's pigweed (*Amaranthus palmeri*), garlic (*Allium sativum*), ginger (*Zingibere officinale*), kudzu (*Pueraria lobata*), and fringed rue (*Ruta chalepensis*). In addition to the use of plant materials, two flavonoids found in kudzu were tested: daidzien (Tokyo Chemical Industry, Tokyo, Japan) and genistien (Alfa Aesar, Ward Hill, Mass.). Fresh garlic and ginger root were purchased from the local grocery store. Kudzu and pigweed were harvested from a local patch along the side of a road. Fresh cuttings of rosemary and rue were collected from local gardens. All plant materials were brought to the laboratory and ground in a food processor (Sunbeam Products, Inc., Boca Raton, Fla.) and/or mortar and pestle. Plant extracts were applied to aliquots of dry *B. glumae* inoculated seeds and kept in sealed plastic Ziploc bags for varying treatment times. A notable exception to this procedure was ginger extract which was applied to the seed and then vacuum infiltrated two consecutive times (25 inch Hg). The kudzu ferment was prepared in a sealed glass jar using 3 g yeast, 3 g sugar, and 20 g root tissue in 200 mL water which was periodically vented to release any built up air pressure. All chemically treated seed was then air dried for 2 h, plated into CCNT media, and allowed to incubate at 39 °C for up to 3 days before scoring for the presence of the *B. glumae* bacteria. A subset of treated seeds was tested for germination by placing seeds on moist filter paper in a petri dish for a week at room temperature in the dark.

Physical Non-Chemical Seed Treatments

Rice seed infused with *B. glumae* was either air dried for 2 h and then placed into envelopes to receive a treatment or treated immediately as wet seed. A 1200 watt microwave (Whirlpool, Benton Harbor, Mich.) was used to process seed with the "cook" setting for various time durations. *Burkholderia glumae* infused seeds and pure lab cultures streaked on King's B media were placed under Versalume UV lamps (Raytech Industries, Middletown, Conn.) for various time durations. The lights were lowered to within 2 inches of the petri dish lid. Inoculated dry seeds were also stored in -20 °C for several days and also treated with hot water from 55 °C to 65 °C.

Field Evaluation on Selected Seed Management Options

Although there were some inconsistent results in the preliminary screening of seed treatment options to BPB disease of rice, Kudzu ferment, 2% vinegar, and dry heat at 55 °C were selected as candidates for field testing in 2013. Heat at 55 °C was considered as a supplementary treatment to vinegar and kudzu ferment. Tests with kudzu ferment in the laboratory were discontinued because its potency varied with time. The 2014 field test was carried out with vinegar alone and vinegar coupled with dry heat at 55 °C.

RESULTS AND DISCUSSION

Managing Seeds for Planting Through Seed Cleaning to Reduce or Eliminate Bacterial Panicle Blight

To remove the light weight infected seeds and chaff from plump healthy-looking seeds, density separation was carried out using aqueous ammonium sulfate solution. Light weight seeds, chaff, and rice residue floated while plump seeds settled in the solution. When tested for the presence of *B. glumae* on CCNT media, all were found positive including the plump seeds (Table 1). However, viable bacteria in each group were not quantified to determine which class of seeds had the potential to introduce more bacteria to the field. When germination of light or plump seeds were tested, the light weight seeds had lower viability which suggested a reduced chance that BPB infected plants originated from floater seeds (Table 1). Moreover, rice chaff gets blown out the back of the combine during harvest, so unless the bacteria survive in the soil for extended periods, chances were low for chaff to contribute to a severe BPB disease situation. This leads to a likely conclusion that the disease is mainly believed to be initiated by seedborne bacteria, so introduction of the bacteria to the field remained possible through all classes of seeds. The number of infected seeds per acre to cause an epidemic under favorable weather conditions remains unknown. Given that the "lighter" seed material was not the only source for bacteria to get introduced into a rice field, removal of lighter seed by the seed industry was not likely going to resolve the spread of bacterial panicle blight in rice fields. Nevertheless, rice growers are advised to plant high quality seeds since such seeds can withstand early growth stress, establish good crop stand, and produce strong seedlings that are more tolerant to early damage by soilborne and seedborne pathogens.

Tests for Seed Dressing Treatments Against Bacterial Panicle Blight Rice Disease

Industrial Products to Control B. glumae. The industrial chemicals tested namely, streptomycin, oxolinic acid, Clorox, vinegar, secure, and isopropyl alcohol showed reduction in recovery of positive seeds for *B. glumae* (Table 2). Streptomycin and oxolinic acid were not viewed as control options in this test but included as a control check. Use of antibiotics in a rice production system was not considered to be sustainable or a responsible solution. Although oxolinic acid is being used to manage rice BPB in other countries such as Japan, resistance to it has already been reported (Maeda et al., 2007) so registration in the U.S. is not likely. When at least 80% seed germination was considered as an acceptable level, the list of unusable products was further narrowed to isopropyl alcohol, Clorox, and distilled vinegar. Although isopropyl alcohol had little effect against the bacteria there were concerns over flammability that would make this chemical unpopular for use by the seed industry. The Clorox appeared to have some control of the bacteria but was not able to eliminate the *Burkholderia*. This was surprising given research that showed that rinsed seeds with Clorox had enough compounds present to prevent bacterial colonies from forming (Miche and Balandreau, 2001). This left vinegar as the only possible chemical control option. Only a 2% vinegar solution showed promise as a control agent against *B. glumae* with a modest reduction in seed germination. When the concentration increased, seed viability decreased. The use of dry heat at 55 °C was also investigated and together with 2% vinegar showed excellent reduction in bacterial recovery without substantial reduction in germination.

Household Chemicals to Control B. glumae. Based on the household chemicals studied, only mouthwash, ammonia, and toilet bowl cleaner showed a reduction in seeds positive for *B. glumae* only when treatment rates and exposure times were increased. As seen with other experiments, high rates of variability in control of the bacteria and reduced germination of seed resulted in no recommendations for BPB disease control (Table 3).

Evaluating Plant Extracts to Control Rice Bacterial Panicle Blight. All of the plant extracts failed to consistently control *B. glumae* that had been artificially applied to the seed. The rue and rosemary extracts (Table 4) performed well in initial tests but the results were not repeatable. This was unexpected given the literature that suggested these plants had antimicrobial properties to gram-negative bacteria (Harish Kumar et al., 2014; Harris et al., 2001; Onyeagba et al., 2004). The possibility existed that anti-bacterial active ingredients were not dissolved in water. There was a conscious decision not to confound the study with use of other solvents i.e., alcohol because this chemical killed bacteria with immense reduction in germination. Flavonoids found in kudzu as daidzien and genistien were not efficacious at reducing bacteria in the seed given the rates and times used individually or combined (Table 4). This was somewhat of a surprise given some encouraging results of activity from kudzu root and stem extracts, as well as kudzu ferments that were at least four months in age. The lack of consistency to eliminate or reduce *B. glumae* with these natural products was possibly related to different batches of extract or ferment that were made using different collections of plant materials at different times. Since any identifiable chemical product was unknown at the time of the study, there was no way to know whether the plant material collected was in optimal condition.

Physical Non-Chemical Seed Treatments

Dry heat was shown to decrease survival of *B. glumae* when applied for at least an hour (Tables 2 and 5). A temperature of 55 °C held for 72 h maximized the kill of bacteria without a substantial decrease in germination. Temperatures above 55 °C greatly decreased seed viability without an added bacterial control benefit. Although the data set was limited, wet seed appeared to react more negatively (reduced seed germ) compared to dry seed treatments. The wet nature of the seed probably allowed for better transfer of heat into the interior of the seed which disrupted sensitive biological processes involved with germination. Microwaving of rice seed proved ineffective in controlling the bacteria. Increasing the duration to almost a minute resulted in the "popping" of the seed which rendered the seed dead (data not shown). Attempts to employ longwave and shortwave UV radiation for up to 24 h proved ineffective in the killing of *B. glumae* both with inoculated seeds and pure culture exposure (data not shown). The standard hot water treatment at 55 °C reduced but did not completely eliminate the *B. glumae* in artificially inoculated seeds. Freezing seeds at -20 °C did not kill the bacteria.

Field Evaluation of Selected Seed Dressing

In 2013, fermented kudzu extract and diluted vinegar (2%) coupled with heat at 55 °C appeared to reduce rice BPB disease. Treatment combination of vinegar and heat lowered the disease considerably compared to the untreated control. When vinegar (2%) coupled with heat was compared to kudzu extract coupled with heat, the former rendered higher BPB disease control and increased grain yield. In 2014, laboratory tests with kudzu ferments were not repeatable due to reduced activity against *B. glumae* that varied with the duration of fermentation and collected plant material. Therefore, the kudzu products were dropped from field testing leaving the vinegar alone and vinegar coupled with heat to be tested using artificially inoculated Bengal seeds. In the 2014 field test, there was a slight reduction in disease for plots planted with treated seeds, but the difference between treated and untreated plots for BPB incidence was not as expected (data not shown). This may be due to the frequent rain that allowed the seed treatments to be diluted or washed away. Regardless of the slight difference in BPB disease, grain yield from the treated plots was slightly higher than the untreated plots (data not shown). Although the results in this study did not show substantial difference in BPB disease reduction, it still remains encouraging to search for better seed management options against BPB. Chemical and non-chemical seed treatments have been useful for managing seedborne diseases in several crops including rice. To date, options using bio-control or microbiological products have not been thoroughly investigated. In-depth evaluation and re-evaluation of chemical and non-chemical seed management options need to continue. In addition to or other than seed treatments, use of resistant rice cultivars and cultural practices should help the grower combat rice BPB disease.

SIGNIFICANCE OF FINDINGS

There remain many challenges with the etiology and epidemiology of bacterial panicle blight for development of sustainable disease management strategies. The use of seed dressing options to manage rice bacterial panicle blight disease was encouraging enough to warrant further investigation with more products. The bacterial pathogen causing bacterial panicle blight was detected in both heavy- and light-weight seed samples. This finding ruled out the short-term control strategy to manage the disease with cleaner seed at the time of planting. Numerous chemical agents were applied to the seed surface as well as vacuum infiltrated into the seed with limited success. Many of the chemicals which strongly inhibited the recovery of *B. glumae* also decreased the germination of the rice seed. A 2% vinegar solution appeared to be the best compromise in the control of bacteria without hurting the seed germ. Various non-chemical methods were investigated and dry heat of 55 °C for 72 h was shown to provide the best control of the bacteria while still maintaining good seed germination. The use of natural product extract or ferment was not successful in reducing *Burkholderia* infected seed to levels appropriate as a control option. In general, these findings seem consistent with the fact that treatment of seeds with sanitizers was not always proven effective in eliminating pathogens (Weissinger and Beuchat, 2000).

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Arkansas Rice Research and Promotion Board for their continued interest and funding of rice pathology research.

LITERATURE CITED

Harish Kumar, K., M. Shanmugavadivu, R. Rajamani, and S. Kuppsamy. 2014. Antibacterial activity of different solvent extracts of medicinal plant: *Ruta graveolens* L. Intl. J. Bioscience and Nanosciences 1:9-11.

Harris, C.J., S.L. Cottrell, S. Plummer, and D. Lloyd. 2001. Antimicrobial properties of *Allium sativum* (garlic). Appl. Microbiol. Biotechnol. 57:282-286.

Kawaradani, M., K. Okada, and S. Kusakari. 2000. New selective medium for isolation of *Burkholderia glumae* from rice seeds. J. Gen. Plant Pathol. 66:234-237.

Maeda, Y., A. Kiba, K. Ohnishi, and Y. Hikichi. 2007. Amino acid substitutions in GyrA of *Burkholderia glumae* are implicated in not only oxolinic acid resistance but also fitness on rice plants. Appl. Envir Microbiol 73:1114-1119.

Miche, L. and J. Balandreau. 2001. Effects of rice seed surface sterilization with hypochlorite on inoculated *Burkholderia vietnamiensis*. Appl. Envir. Microbiol. 67:3046-3052.

Nandakumar, R., A.K.M. Shahjahan, X.L. Yan, E.R. Dickstein, D.E. Groth, C.A. Clark, R.E. Cartwright, and M.C. Rush. 2009. *Burkholderia glumae* and *B. gladioli* cause bacterial panicle blight in rice in the southern United States. Plant Dis. 93:896-905.

Onyeagba, R.A., O.C. Ugbogu, C.U. Okeke, and O. Iroakasi. 2004. Studies on the antimicrobial effect of garlic (*Allium sativum* Linn), ginger (*Zingiber officinale* Roscoe) and lime (*Citrus aurantifolia* Linn). African J. Biotech 3:552-554.

Streeter, J.G. 2007. Factors affecting the survival of *Bradyrhizobium* applied in liquid cultures to soya bean [*Glycine max* (L.) Merr.] seeds. J. Appl. Micro. 103:1282-1290.

Weissinger, W.R. and L.R, Beuchat. 2000. Comparison of aqueous chemical treatments to eliminate *Salmonella* on alfalfa seeds. J. Food Prot. 63:1475-1482.

Table 1. Detection of *Burkholderia glumae* and germination test of two classes of Clearfield rice seed varieties harvested from bacterial panicle blight infected plots during 2011.

Variety	Class	Study#1[a] bacteria found	Study#2[a] bacteria found	Study #3[b] bacteria found	Germ
					(%)
CL111	Floater[c]	-	-	-	21
	Sinker	-	+	-	90
CL142AR	Floater	+	+	+	1
	Sinker	+	+	+	36
CL151	Floater	+	-	-	9
	Sinker	+	+	+	79
CL152	Floater	+	+	+	13
	Sinker	+	-	+	91
CL162	Floater	+	-	-	19
	Sinker	+	+	+	87
CL181AR	Floater	-	-	-	2
	Sinker	-	+	+	71

[a] Seed ground in extraction buffer with extract spotted on CCNT media.
[b] Seed ground in water with extract spotted on selection media.
[c] Contained underdeveloped seed, chaff, and other vegetative tissues.

Table 2. Effect of industrial chemicals on *B. glumae* in inoculated seed and germination.

Treatment	Concentration[a]	Treatment duration	Positive seeds for *Bg*	Germination
	(g product/kg seed)	(h)	---------------- (%)	----------------
Bg wet seed only (ctrl)	na	20-144	99	na
Bg dry seed only (ctrl)	na	1-144	81	89
Bg dry seed + 55°C (ctrl)	na	1-144	0	86
Silver compound (wet seed)	0.4	20-144	20	na
Streptomycin (wet seed)	0.2	20-144	13	na
Kocide 2000 (wet seed)	1.4	20-144	84	na
Oxolinic acid (wet seed)	A	20-144	0	na
Mankocide (Cu/Zn) (wet seed)	7.5	5	100	na
Clorox full strength (dry seed) + 52 °C	B	0.17	10	60
Clorox half strength (dry seed) + 52 °C	C	0.17	18	90
Distilled vinegar ¼ strength (dry seed)	D	72	45	86
		144	25	89
Distilled vinegar ½ strength (dry seed)	E	72	5	71
		144	12	77
Distilled vinegar full strength (dry seed)	F	1	0	25
		24	0	0
Distilled vinegar + 55 °C (dry seed)	D	72	0	78
		144	0	71
Distilled vinegar + 55 °C (dry seed)	E	72	0	34
	144	0	25	
Cecure® CPC (dry seed)[b]	40	1	7	40
		20	100	na
Cecure® CPC (dry seed)	160	1	0	40
		20	23	na
Peroxide (wet seed) vacuum infiltrated	C	0.05	100	na
Isopropyl alcohol (dry seed)	G	0.17	100	50
Isopropyl alcohol (dry seed) + 52 °C	G	0.17	97	80
Isopropyl alcohol (dry seed) + 52 °C	H	0.17	50	80

[a] A = 0.5% solution; B = 6% solution; C = 3% solution; D = 1% solution; E = 2% solution; F = 5% solution; G = 17.5% solution; H = 8.75% solution; and I = slurry made as 4 g product/4 mL water and then applied to seed + continuous exposure.

[b] CPC = cetylpyridinium chloride.

Table 3. Effect of household chemicals on *B. glumae* in inoculated seed and germination.

Treatment	Concentration[a]	Treatment duration	Positive seeds for *Bg*	Germination
	(g product/kg seed)	(h)	---------------- (%)	----------------
Mouthwash (dry seed)	48	3	80	70
	96	3	100	80
	96	24	17	40
	192	24	0	1
Toilet bowl cleaner (dry seed)	48	3	33	60
	96	3	20	70
	96	24	57	80
	192	24	0	60
Ammonia cleaner (dry seed)	48	3	100	80
	96	3	77	50
	96	24	3	1
	192	24	0	0
Toothpaste (dry seed)	[a]	2	93	na
	[a]	24	77	na

[a] Slurry made as 4 g product/4 mL water and then applied to seed.

Table 4. Effect of plant extracts on *B. glumae* in inoculated seeds and germination.

Treatment	Extract	Concentration[a]	Treatment time	Positive seeds for *Bg*	Germination
	(g tissue/200 mL water)	(mL extract/3 g seed)	(h)	------ (%) ------	
B. glumae only	na	na	1	100	90
		na	24	97	90
Fresh garlic extract	[b]	1.5	1	30	70
		1.5	24	0	40
50% fresh garlic extract	[b]	1.5	1	63	80
		1.5	24	27	50
Pigweed extract	5	1.5	1	50	50
		1.5	24	6	50
Fresh kudzu root extract	5	3	24	20	64
Kudzu stem extract	5	3	24	6	76
Kudzu young leaves	5	3	24	27	64
Kudzu 2 month old ferment	20	0.9	144	55	86
Kudzu 4 month old ferment	20	0.9	72	23	85
Kudzu 5 month old ferment	20	0.9	72	23	90
Daidzien	na	A	24	26	88
Genistien	na	A	24	51	77
Daidzien + Genistien	na	B	24	63	90
Ginger extract vacuum infiltrated	5	1.5	0.08	43	na
Rue extract	5	3	1	100	70
		3	24	0	80
Rosemary extract	5	3	1	93	80
		3	24	0	60
Rosemary + Rue extract	5	3	1	100	90
		3	24	0	40

[a] A = 300 mg chemical/20 g seed; B = 150 mg chemical each/20 g seed.
[b] 3 bulbs pressed yielded 40 mL extract.

Table 5. Effect of non-chemical treatments on *B. glumae* in inoculated seeds and germination.

Treatment	Treatment time	Positive seeds for *Bg*	Germination
	(h)	--------------------(%)	------------------
B. glumae only (control)	na	100	90
40 °C heat	1	98	na
40 °C heat	24	10	na
55 °C heat	72	0	90
65 °C heat	72	0	15
Heat wet seed 49 °C	48	0	70
Freeze wet seed -20 °C	48	100	0
Hot water 55 °C	0.025	15	50
Microwave	0.00278	100	90
	0.00556	50	80

Disease Component Analysis of the Infection of Four Rice Cultivars, Jupiter, Katy, Neptune, and Roy J, by an Albinotic Strain of the False Smut Pathogen Recently Found in Arkansas

D.O. TeBeest and A.C. Jecmen

ABSTRACT

False smut of rice has recently emerged as an important disease of rice in Arkansas. In 2011, 2012, and 2013, sori of a white smut were observed in two rice fields in eastern Arkansas. Since white false smut is relatively new and still very uncommon in Arkansas, we examined the virulence of one of the isolates of white smut that we had collected to four current or previously important medium- and long-grain rice cultivars in greenhouse tests. These cultivars had appeared to differ in susceptibility to green smut in repeated field tests. Repeated experiments were designed and conducted in a greenhouse to measure three disease components including infection efficiency, sporulation, and latent period. Our results indicate that although the white isolate of false smut is virulent to the four rice cultivars in greenhouse tests, there are differences in the reaction of the cultivars to this isolate. Infection efficiency, measured as the ratio of infected to inoculated panicles, varied by cultivar and panicle developmental stage while sporulation, measured as the number of sori produced per panicle, varied among the cultivars. In repeated tests, Roy J appeared to be highly susceptible to the white isolate with an average infection efficiency rating of 0.49 and an average of 3.7 sori per infected panicle. On the other hand, Jupiter appeared to be the most resistant of the four cultivars tested, with an average infection efficiency of 0.06 and an average of 2.0 sori per panicle. The long-grain cultivar Katy had an infection efficiency rating of 0.24 and an average of 4.2 sori per panicle. The data confirm our previous report that the white isolate used in the tests is virulent to rice grown in Arkansas; but, the data also show that the procedures used to evaluate the virulence of the white isolate may provide a mechanism to identify differences among cultivars for resistance to this and other isolates of this pathogen.

INTRODUCTION

Green false smut (GFS) of rice is caused by the fungus *Ustilaginoidea virens* (Cke) Tak. (teleomorph = *Villosiclava virens* (*V. Sakurai* ex Nakata) E. Tanaka & C. Tanaka (Tanaka et al., 2008; Wang et al., 2008). Green false smut has been in the United States for many years, but was first reported in Arkansas in 1997 and is now found throughout the state (Cartwright et al., 1999; Wilson et al., 2005). The disease cycle and the epidemiology of *U. virens* is not well understood (Lee and Gunnell, 1992; Tang et al., 2012) although recent clarifications have been made (Ashizawa et al., 2011, 2012; Chen et al., 2013; TeBeest and Jecmen, 2013; Tanaka et al., 2008; Wang et al., 2008). Reports suggest that GFS is now of worldwide importance and that it can reduce yields (Cartwright et al., 1999; Hegde and Anahosur, 2000). The production of ustiloxin, an inhibitor toxic to animals, in sori affects quality (Koiso et al., 1994; Luduena et al., 1994; Miyazaki et al. 2009).

The appearance of the sori of GFS coincides with flowering when grains develop into sori enclosed in a gray membrane. Over time and with further growth, the membranes break and release the orange spores that rapidly become dark green or black later in the growing season (Lee and Gunnell, 1992). Low temperatures and moisture at heading are involved in the expression of sori and disease (Ashizawa et al., 2011; Guo et al., 2012; Wang et al., 2008). The entire process of sori development, from first swelling to maturation as blackened sori occurs over a two week period in Arkansas (TeBeest and Jecmen, 2013).

In 2014, Jecmen and TeBeest (2014a) observed a white false smut previously described by Wang and Bai (1997) on panicles of two American rice cultivars growing in fields in two counties in Arkansas. Although the morphology and coloration of the isolates of white smut found in Arkansas were different from the green isolates of false smut, the ribosomal DNA sequences were similar for both green and white isolates. Jecmen and TeBeest (2014a,b) also showed that the white isolates were virulent to two rice cultivars grown in Arkansas. The earlier reports did not determine if different cultivars of rice grown in Arkansas varied in resistance to white smut.

The objectives of this research were to determine the effect of post-inoculation dew and irrigation treatments on the incidence of false smut; and to determine the effect of growth medium, cultivar, and panicle differentiation on the relative susceptibility of rice cultivars to false smut as measured by disease components that quantitatively measure infection efficiency, sporulation, and latent period of the white smut isolate recently found in Arkansas.

MATERIALS AND METHODS

Plants

Seeds of rice cultivars Jupiter, Katy, Neptune, and Roy J were sown in 2 inch Jiffy peat-pots on 27 January 2014 containing field soil from a fallow field obtained at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station near Newport, Ark. In these experiments, seedlings at the V3 and V4 stages

(Counce et al., 2000) were transplanted into one gal plastic pots containing the same soil from Newport. Pots were individually placed into five gal buckets then sub-irrigated to maintain a 5 cm (2 inch) water level in the buckets. Approximately 5 to 7 g (1 tsp) of urea fertilizer was applied to the 5 cm water in each bucket to promote tiller development. Buckets were flooded to 5 to 10 cm (2 to 4 inches) above the soil line when plants reached the V5 and V6 stages of development.

Fungus

Cultures of the white false smut isolate, I-9E, were grown and maintained on potato dextrose agar (PDA) in petri dishes. In the first experiment, 7-mm agar plugs were taken from actively growing PDA cultures and transferred to 25 mL of wheat bran broth (WBB). In the second experiment, 7-mm agar plugs were transferred to 25 mL of potato dextrose broth (PDB) or rice brand broth (RBB). All broth cultures were incubated at 21 °C for 7 to 10 days on a Junior Orbit Shaker at 125 rpm (Lab-Line Instruments Inc. Melrose Park, Ill.). To prepare inoculum, 15 mL of broth culture and 30 mL of water was added to 50 mL centrifuge tubes and centrifuged at 7500 rpm for 5 min. The broth liquid was decanted and the cultured tissue and spores were re-suspended in distilled water to 5.0 to 10.0 × 10^4 spores per mL.

Inoculation

The first experiment was conducted in order to optimize the post-inoculation conditions that are reported to influence the development of disease after inoculation of panicles enclosed within the flag leaf sheaths. In these experiments, the developing panicles within the flag leaf sheaths were inoculated with 1 mL of spore suspensions containing 1 × 10^4 spores per mL obtained from 7 to 10 day old WBB cultures. After inoculation, the plants within the individual pots were subjected to one of four treatments to test the requirements for post-inoculation free moisture requirements. These treatments consisted of the following: 1) a dew period of 48 h at 20 °C followed by incubation in the greenhouse, 2) placing plants in a rain tunnel for overhead irrigation without a dew period, 3) giving inoculated plants a 48 h dew period at 20 °C followed by overhead irrigation in a rain tunnel, and 4) no dew period or rain tunnel treatment after inoculation. The rain tunnels were created with opaque plastic sheeting (1.5 m high × 1.5 m wide × 10 m long) in the greenhouse. Overhead irrigation (representing rain) was supplied for 5 min every 2 h inside the enclosure using impulse sprayers (Fig. 1; R. Padula Enterprises, New York, N.Y.). The experiment consisted of three pots per treatment, with approximately four panicles inoculated per pot. The experiment was completed twice in a completely randomized block design with three replications of each treatment in each experiment. Controls consisted of non-inoculated panicles within each pot. Each panicle on each plant in each pot was labeled to facilitate data collection. At the end of this experiment, when panicles had reached midmaturity, the size of a representative and random group of sori were also measured to determine if post-inoculation treatments affected sori development. In the second experiment, plants were inoculated between the R2 and R3 stages at several different stages of panicle maturity. In this experiment, plants were inoculated with spores obtained from RBB, PDB, or WBB. The stage of each panicle was determined by measuring the distance between the flag and penultimate leaf collars at the time of inoculation. Panicle stages are as follows: 1 = 0 to 2 cm; 2 = 2 to 4 cm; 3 = 4 to 6 cm; 4 = 6 to 8 cm; 5 = 8 to 10 cm; 6 = 10 to 12 cm; and, 7 = 12 cm or greater.

The panicles were inoculated at approximately 1 to 2 cm below the flag leaf and approximately 0.5 to 1.0 above the tip of the immature panicle with approximately 0.8 to 1.0 mL of inoculum prepared from WBB. The controls consisted of panicles that were not inoculated in each pot. Inoculated plants were placed into a dew chamber set to maintain 20 °C for 48 h. Based on the results of the first experiment, all plants were returned to the greenhouse and placed within the plastic enclosure and irrigated for 5 min every 2 h. The inoculated and control panicles were examined daily after plants were removed from the dew chamber to identify the first day on which the first sori appeared. The total number of sori on the infected panicles was counted on two- to five-day intervals beginning on the date of the first appearance of a sorus on each panicle. This experiment consisted of four treatments with three replications of each treatment arranged in a completely randomized block design in the greenhouse after inoculation. The experiment was conducted twice.

RESULTS AND DISCUSSION

The research reported here was conducted under highly controlled conditions in a greenhouse in the University of Arkansas System Division of Agriculture's Rosen Center, Fayetteville, Ark., to determine if an albinotic strain of false smut is virulent to four rice cultivars (Katy, Jupiter, Neptune, and Roy J) grown in Arkansas. Panicles of each of the cultivars were inoculated by injection of spores of isolate I-9E harvested from broth cultures into panicles at different developmental stages.

The results of the experiments testing the effects of post-inoculation moisture treatments are presented in Table 1. In the first experiment, a total of 94 panicles were inoculated. The number of panicles inoculated per treatment ranged from 21 to 25. The data in Table 1 show that 60% of the panicles inoculated that received a dew period produced at least one sorus. Thirty two percent of the 25 panicles receiving dew and post-dew overhead irrigation treatments produced at least one sorus. Only 8 and 5 panicles receiving post inoculation dew and overhead irrigation or no post inoculation treatment at all, respectively, produced at least one sorus per panicle.

In addition, there were significant differences among the treatments in the types of sorus observed. On plants subjected to post-inoculation overhead irrigation treatment (irrigated and dew plus irrigated), sori developed into well differentiated structures as shown in Fig. 2. On plants subjected to the two other treatments, (dew only and no dew or overhead irrigation) the sori did not differentiate into the expected well known structure associated with false smut. The number of sori produced on infected panicles ranged from 1.1 following a dew period only, treatment 1 to 2.75 per panicle for the dew plus irrigated treatment 3. The average number of sori per panicle on Roy J in this test for treatments 2 and 4 was approximately 2 sori per panicle. However, and more importantly, sori produced on panicles subjected to treatments 1 and 4 were smaller and often did not develop well enough to separate the glumes on affected grains (Fig. 3). Results of statistical tests (*t* and *F* tests, Steele and Torrie, 1960) on unequal sample sizes (n = 22 for treatments 2 and 3, and n = 33 for treatments 1 and 4) showed that the average size of sori for treatments 2 and 3 was 5.48, significantly larger than the average size for sori found on grains in treatments 1; and 4 was 1.48, at $P = 0.01$ (data not shown). This was unexpected but might explain the origin of the 'chaffiness' often associated with false smut of rice as reported by many investigators. Further, the effects of post-inoculation overhead irrigation on the development of mature well developed sori might help explain why the disease is often associated with periods of rainfall at heading of rice by investigators worldwide. These two types of sori found in our experiments resemble the two types of infection first described by Raychauduri (1946).

In the second experiment, the stages at which panicles were inoculated are arbitrary and based on the distance between the flag and penultimate leaves at the time of inoculation. For example, at stage 1, panicles were inoculated when the distance between the penultimate leaf and the flag leaf was only 0 to 2 cm; whereas stages 2, 3, 4, 5, 6, and 7 were inoculated when the distances were between 2 to 4 cm, 4 to 6 cm, 6 to 8 cm, 8 to 10 cm, 10 to 12 cm, and greater than 12 cm, respectively. In this report, a total of 849 panicles were inoculated with inoculum containing spores of I-9E; 183 of Neptune, 158 for Roy J, 215 for Katy, and 293 for Jupiter. In addition, 274 panicles served as controls after inoculation with water; 44 for Neptune, 43 for Roy J, 92 for Katy and 95 for Jupiter. After inoculation, all plants were first placed in a dew chamber at 20 °C for 48 h. Then they were returned to the greenhouse where the plants were irrigated by overhead sprinklers (Fig. 1) for 5 min every 2 h. The experiments were concluded after incubation for 30 days in the greenhouse.

The combined data from experiment 2 in this study suggest that the inoculum prepared from the different media were not uniformly effective in causing disease (data not shown). Successful infection was assessed as the production of sori as shown in Fig. 2. In this study, only 6 of the 244 panicles inoculated with inoculum prepared from RBB produced sori (3 on Roy J and 3 on Katy). On the other hand, 67 of the 308 panicles inoculated with inoculum prepared from WBB produced sori (8 on Neptune, 36 on Roy J, 20 on Katy, and 3 on Jupiter). In addition, 56 of the 297 panicles inoculated with spores prepared from PDB cultures produced sori (7 on Neptune, 22 on Roy J, 16 on Katy, and 11 on Jupiter). None of the panicles inoculated with water produced sori.

The results of this study shown in Table 2, show that an albinotic strain (I-9E) of false smut described by Jecmen and TeBeest (2014a,b) is virulent to Katy, Jupiter, Roy J, and Neptune. The signs of infection, the sori, were very similar in size and morphology to those described in the original report for all four of these cultivars and to the size and morphology of sori that developed in experiment 1 following post-inoculation overhead irrigation.

The latent period, the average time between inoculation and the first appearance of sori, measures the virulence of an isolate or pathogen to hosts that may vary in resistance to that pathogen (Zadoks and Schein, 1979). In this study, the latent period was determined to be approximately 15 to 17 days after inoculation across the four cultivars. It should be noted that sori generally appeared within 7 to 10 days after the emergence of the panicle from the boot.

Sporulation (a measure of infectiousness) is an essential factor in disease component analysis (Zadoks and Schein, 1979). It estimates the relative contribution of spores to an epidemic. As defined here, sporulation is simply the average number of sori found on the visibly infected panicles. The data in Table 2 show that there was an average of 1.55 and 2.0 sori per infected panicles for Neptune and Jupiter, respectively. Further, the data show that there was an average of 3.7 and 4.2 sori per infected panicle for Roy J and Katy, respectively. Thus, the albinotic strain, I-9E, produced approximately two times more sori per panicle on the two long-grain cultivars than on the two medium-grain cultivars in these experiments.

The infection efficiency (IE) is usually defined as the ratio of the number of sori produced to the number of spores applied (Zadoks and Schein, 1979) but in this paper it is defined as the ratio of the number of panicles infected to the number of panicles inoculated. The calculated IE varied across cultivars in these experiments (Table 2). For example, the IE of medium-grain cultivars, Neptune and Jupiter, was 0.12 and 0.06, respectively. In contrast, the IE of the two long-grain cultivars in these experiments, Roy J and Katy, was 0.49 and 0.24, respectively. Thus, the data suggests that it was more efficient to induce disease development in the two long-grain cultivars than in the two medium-grain cultivars.

However, in these experiments we also inoculated panicles of the different cultivars at seven stages of panicle development in order to determine if the panicles were susceptible to the fungus at the different stages of maturity. The data in Table 3 shows that the IE of each of the four cultivars varied according to the stages that the panicles were in at the time of inoculation. For example, the data suggest that the IEs of both medium-grain cultivars, Neptune and Jupiter, were below 0.20. Further, very few of the panicles were infected when panicles larger than 10 to 12 cm in length were inoculated. On the other hand, the IEs for Roy J and Katy were greater, and successful inoculations were made at all panicle stages. The most susceptible cultivar (Roy J) to isolate I-9E had an IE of 83% when inoculated at developmental stage 2, gradually descending in efficiency to stage 7 when only 35% of the inoculations were successful. Somewhat surprisingly, the IE for Katy was approximately 25% across all developmental stages, higher than that for either Jupiter or Neptune when inoculated at the same stages with the same isolate. In previous reports, Katy was described as more resistant to green smut than the other cultivars tested (TeBeest and Jecmen, 2013).

SIGNIFICANCE OF FINDINGS

The results of this study show that an albinotic strain of false smut is virulent to Katy, Jupiter, Roy J, and Neptune. Further, the appearance and morphology of the sori were very similar across all four of these cultivars in the greenhouse and in the field as reported by Jecmen and TeBeest (2014a). Although this white smut isolate was found by the investigators in two fields in Arkansas, it is still highly limited in occurrence within the state.

The four cultivars chosen in this report represented the observed differences to false smut in field experiments testing 12 cultivars for resistance to false smut (TeBeest and Jecmen, 2013). For example, Katy and Jupiter were considered to be relatively resistant to false smut because they exhibited small levels of infection in repeated field experiments. In comparison, Roy J and Neptune were both considered to be relatively susceptible to the green smut found in these same field studies (TeBeest and Jecmen, 2013) since each exhibited higher levels of infection in comparison to Katy and Jupiter. Two cultivars, Jupiter and Neptune, are both medium-grain cultivars while Katy and Roy J are both long-grain cultivars.

Disease component analysis (DCA) is an essential tool for evaluation of disease resistance to a pathogen or to strains or isolates of that pathogen (Zadoks and Schein, 1979). Latent period, lesion growth rates, sporulation, and infection efficiency assessments are common tools in DCA. All four assessments require visible signs or symptoms of infection. But, the production of sori in controlled conditions has been difficult to achieve reproducibly in the greenhouse and in the field. The ability to produce sori after inoculation is an essential requirement in order to measure these common assessment tools (TeBeest and Jecmen, 2014). The data describing three of the four disease components described by Zadoks and Schein also suggest that some cultivars appear to be differentially resistant/susceptible to false smut. Comparison of the data from previous reports with the data shown here suggests that the white smut isolate may be more virulent to Katy than the green false smut isolates infecting Katy in the field. However, only direct and simultaneous comparisons using the basic methodology reported here with individual isolates can identify differential virulence and susceptibility of specific isolates and cultivars, respectively.

Disease is the result of the interaction of host, pathogen, and environment. The results of the greenhouse evaluations presented here have further defined the environmental conditions required for development of the fully developed sori on rice panicles under carefully defined conditions. It has been reported that the disease is most common during wet weather and that misting of plots facilitated the production of high levels of disease (Kulkarni and Moniz,1975). Jecmen and TeBeest (2014a) reported that a brief exposure of infected panicles to rain or dew appeared to have contributed to an increase in sori on plants they inoculated in a greenhouse. The use of the intermittent misting of the inoculated panicles after a dew period and during the exertion of panicles from the boots in the greenhouse appears to have been a helpful, if not an essential factor, in providing conditions necessary for sori to develop under otherwise dry and adverse conditions. It is interesting that these conditions closely resemble those conditions thought necessary for development of the disease in the field as described by several investigators.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Director of the University of Arkansas System Division of Agriculture's Agricultural Experiment Station and for the support of the Arkansas Rice Research and Promotion Board of Arkansas through grants to DTB. This work was also supported, in part, by the USDA National Institute of Food and Agriculture, Hatch Project no. 1004183.

LITERATURE CITED

Ashizawa, T., M. Takahashi, J. Moriwaki, and K. Hirayae. 2011. A refined inoculation method to evaluate false smut resistance in rice. J. Gen. Plant Pathol. 77:10-16.

Ashizawa, T., M. Takahashi, M. Arai, and T. Arie. 2012. Rice false smut pathogen, *Ustilaginoidea virens*, invades through small gap at the apex of a rice spikelet before heading. J. Gen. Plant Pathol. 78:255-259.

Cartwright, R.D., F.N. Lee, C.E. Parsons, W.J. Ross, S.R. Vann, and R. Overton. 1999. Monitoring of rice diseases and on-farm evaluation of rice varieties in Arkansas. *In:* R.J. Norman and T.H. Johnston (eds). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Series 468:148-156. Fayetteville, Ark.

Chen, Y., Y. Zhang, J. Yao, Y.-F. Li, X. Yang, W.-X.Wang, A.-F. Zhang, and T.-C. Gao. 2013. Frequency distribution of sensitivity of *Ustilaginoidea virens* to four EBI fungicides, prochloraz, difenoconazole, propiconazole, and tebuconazole, and their efficacy in controlling rice false smut in Anhui Province of China. Phytoparasitica 41:277-284.

Counce, P.A., T.C. Keisling, and A.J. Mitchell. 2000. A uniform, objective, and adaptive system for expressing rice development. Crop Sci. 40:436-443.

Guo, X., Y. Li, J. Fan, L. Li, F. Huang, and W. Wang. 2012. Progress in the study of false smut disease in rice. J. Agric. Sci. Tech. A2:1211-1217.

Hegde, Y.R. and K.H. Anahosur. 2000. Effect of false smut of rice on yield components and growth parameters. Indian Phytopathol. 53:181-184.

Jecmen, A.C. and D.O. TeBeest. 2014a. First report of the occurrence of a white smut infecting rice in Arkansas. J. Phytopathology 163:138-143.

Jecmen, A.C. and D.O. TeBeest. 2014b. A preliminary study of a white smut infecting rice in Arkansas. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:101-108. Fayetteville, Ark.

Koiso, Y., Y. Li, S. Iwasaki, K. Hanoaka, T. Kobayashi, R. Sonoda, Y. Fujita, H. Yaegashi, and Z. Sato. 1994. Ustiloxin, antimitotic cyclic peptides from false smut balls on rice panicles caused by *Ustilaginoidea virens*. J. Antibiot 47:765-773.

Kulkarni, C.S. and L. Moniz. 1975. False smut of rice—an airborne disease. Current Science 44:483-484.

Lee, F.N. and P.S. Gunnell. 1992. False Smut. p. 28. *In:* R.K. Webster and P.S. Gunnell (eds.). Compendium of Rice Diseases. American Phytopathological Society, St. Paul, Minn. USA.

Luduena, R.F., M.C. Roach, V. Prasas, M. Banerjee, Y. Koiso, Y. Li, and S. Iwasaki. 1994. Interactions of ustiloxin A with bovine brain tubulin. Biochem Pharmacol 47:1593-1599.

Miyazaki, S., Y. Matsumoto, T. Uchihara, and K. Morimoto. 2009. High-performance liquid chromatographic determination of ustiloxin A in forage rice silage. J. Vet. Med. Sci. 7:239-241.

Raychaurduri, S. 1946. Mode of infection of rice by *Ustilaginoidea virens* (CKE) Tak. J. Indian Bot. Soc. 25:145-159.

Steele, R.G.D and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. New York, N.Y. 481 pages.

Tanaka, E., T. Ashizawa, R. Sonoda, and C. Tanaka. 2008. *Villosiclava virens* gen. nov., com., nov., teleomorph of *Ustilaginoidea virens*, the causal agent of rice false smut. Mycotaxon 106:491-501.

Tang, Y.-X., J. Jin, D.-W. Hu, M.-L.Yong, and L.-P. He. 2012. Elucidation of the infection process of *Ustilaginoidea virens* (teleomorph: *Villosiclava virens*) in rice spikelets. Plant Pathology 1-8.

TeBeest, D.O. and A.C. Jecmen. 2013. Reactions of selected rice cultivars to *Ustilaginoidea virens* in Arkansas. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:77-88. Fayetteville, Ark.

TeBeest, D.O. and A.C. Jecmen. 2014. Colonization of rice folrets and the development of sori on rice culturivars susceptible to *Ustilaginoidea virens*. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:116-132.

Wang, S. and J.K. Bai. 1997. A new species of *Ustilaginoidea*: *U. albicans*. Mycostema 16:257-258.

Wang, S., M. Li, H. Dong, X.-Z. Liu, Y.-J. Bai, and H. Yang H. 2008. Sporulation, inoculation methods and pathogenicity of *Ustilaginoidea albicans*, the cause of white rice false smut in China. J. Phytopathology. 156:755-757.

Wilson, C.E., R.D. Cartwright, J.W. Gibbons, A.L. Richards, D.L. Frizzell, J.W. Branson, S. Runsick, and C.E. Parsons. 2005. Evaluation of rice varieties for performance and disease reaction on farms. *In:* R.J. Norman, J.-F. Muellenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2004. University of Arkansas Agricultural Experiment Station Research Series 524:149-158. Fayetteville, Ark.

Zadoks, J.C. and R.D. Schein. 1979. Epidemiology and plant disease management. Oxford University Press. New York, N.Y. 427 pages.

Table 1. The effect of post-inoculation dew and overhead irrigation treatments on the subsequent development and incidence of sori on panicles of the cultivar Roy J[a] of *Oryza sativa*. In these fully replicated experiments, panicles enclosed with the flag leaf sheath at "booting" were inoculated with spores of an albinotic strain of *Ustilaginoidea virens* recently found in Arkansas.

Treatment[b]	Total panicles inoculated	No. of panicles infected	Infection efficiency[c]	Total no. sori observed[d]	No. of sori per infected panicle
(Description)	------------------ (no.)	--------------------	(%)	------------------ (no.)	-------------------
1 (Dew)	25	15	60	27	1.1
2 (Irrigated)	23	2	8.7	4	2.0
3 (Dew + irrigated)	25	8	32	22	2.75
4 (None)	21	5	23.8	9	1.8

[a] In these experiments, seeds of the rice cultivar Roy J were obtained from the Rice Research and Extension Center, near Stuttgart, Ark.

[b] The four treatments in this study consisted of the following post-inoculation treatments: 1) the dew treatment consisted of placing inoculated plants in a dew chamber for 48 h at 20 °C then returning them to the greenhouse bench, 2) the Irrigated treatments consisted of placing inoculated plants in a tunnel and spraying the plants by overhead sprinklers, 3) the dew plus irrigated treatment consisted of placing plants in the dew chamber as in treatment 1 followed by placing them in a tunnel for overhead irrigation as in treatment 2, and 4) placing plants on the greenhouse bench immediately after inoculation without any dew or irrigation treatment. Controls in all cases consisted of plants within the pots that were not inoculated with *U. virens* but subjected to the same post inoculation treatments.

[c] Infection efficiency is expressed as the fraction of the number of panicles visibly infected with sori of the fungus divided by the number of panicles inoculated with spores of the fungus.

[d] In this report, sporulation is defined as the average number of sori found on infected panicles for each cultivar after inoculation with spores collected from wheat bran broth and potato dextrose broth. All of the inoculated panicles were observed at two day intervals after inoculation and removal from the dew chambers. In these experiments, any grain was considered to be colonized (= sorus) by *U. virens* if a white fungal-like growths was observed forcing apart the glumes of affected seeds (Fig. 3). These glumes were often light brown in color and separated from the sorus materials. A sorus was considered as mature if it had grown to a size and morphology similar to those normally associated with this disease (Fig. 4).

Table 2. Results of disease component analysis of the infection of four rice cultivars grown in Arkansas by an albinotic strain (I-9E) of *Ustilaginoidea virens*. In these tests, panicles of different stages of development were inoculated by injection of spores into the developing panicles followed by placing inoculated plants in a dew chamber at 20 °C for 48 hours. After the dew period, plants were incubated in a greenhouse within plastic enclosures and all plants were subjected to overhead irrigation for five minutes every two hours for three weeks following inoculation.

Cultivar[a]	Infection efficiency[b]	Sporulation[c]	Latent period[d]
Jupiter	0.06	2.0	15
Neptune	0.12	1.55	16.6
Katy	0.24	4.2	15.7
Roy J	0.49	3.7	15.4

[a] Four rice cultivars were used in the tests. Two cultivars, Jupiter and Neptune are medium-grain cultivars while Katy and Roy J are both long-grain cultivars. Seeds of the cultivars were originally obtained from the Rice Research and Extension Center near Stuttgart, Ark.

[b] Infection efficiency is expressed as the fraction of the number of panicles visibly infected with sori of the fungus divided by the number of panicles inoculated with spores of the fungus.

[c] In this report, sporulation is defined as the average number of sori found on infected panicles for each cultivar after inoculation with spores collected from wheat bran broth and potato dextrose broth.

[d] In this report, latent period is the time required for sori to appear on a panicle after inoculation with spores of the fungus. Latent period is expressed as the average number of days after inoculation for visible sori to appear.

Table 3. The table shows the effects of inoculation of panicles at several developmental stages on the infection efficiency of the albinotic strain (I-9E) on four rice cultivars grown in Arkansas. In these tests, panicles of seven different stages of development were inoculated by injection of spores into the developing panicles followed by placing inoculated plants in a dew chamber at 20 °C for 48 hours. After the dew period, plants were then incubated in a greenhouse in the Rosen Center within a plastic enclosure in which all plants were subjected to overhead irrigation for five minutes every two hours for an additional three weeks.

Panicle	Medium-grain cultivars		Long-grain cultivars	
stage[a, b]	Jupiter	Neptune	Katy	Roy J
1	0.17[c]	0.0	0.29	0.50
2	0.06	0.15	0.36	0.83
3	0.08	0.16	0.27	0.74
4	0.06	0.03	0.24	0.60
5	0.0	0.04	0.21	0.50
6	0.0	0.16	0.16	0.39
7	0.0	0.0	0.16	0.35

[a] Due to the simultaneous and interacting constraints of asynchronous plant development and limited space available within the greenhouse, the number of panicles within each panicle developmental stage was unequal.

[b] In these tests, panicle stage is based upon the distance (in cm) between the flag leaf and the penultimate leaf at the time of inoculation. Panicle stages are as follows: 1 = 0 to 2 cm; 2 = 2 to 4 cm; 3 = 4 to 6 cm; 4 = 6 to 8 cm; 5 = 8 to 10 cm; 6 = 10 to 12 cm; and, 7 = 12 cm or greater.

[c] In these tests, infection efficiency is defined as the ratio of the number of panicles infected divided by the total number of panicles inoculated at each of the seven developmental stages. Thus, an infection efficiency of 1.0 indicates that all (100%) of the panicles inoculated with strain I-9E developed mature sori at the end of the incubation period of 28 days.

Fig. 1. Irrigation system used in the greenhouse experiments. The sprinkler head is shown in the foreground.

Fig. 2. Mature sori of an albinotic strain of the false smut pathogen produced on a rice panicle after inoculation with spores.

Fig. 3. An underdeveloped sorus of *Ustilaginoidea virens*, isolate I-9E, found on rice cultivar Roy J after incubation in a greenhouse for three weeks without supplemental overhead irrigation. In this example, the sorus has forced apart the glumes of a rice grain but has not expanded as expected.

Characterization of Rice Germplasm for Genetic Resistance to Bacterial Panicle Blight Disease and Development of Techniques for Monitoring the Bacterial Pathogen

Y.A. Wamishe, Y. Jia, T. Gebremariam, C. Kelsey, S. Belmar, and T. Mulaw

ABSTRACT

A study was continued in 2014 to understand *Burkholderia glumae*, the major causal agent for bacterial panicle blight (BPB) disease of rice, to evaluate rice germplasm for resistance and to develop practical diagnostic methods for monitoring the disease. Symptomatic panicles were collected from the Arkansas Rice Performance Trials (ARPT) and the Producer Rice Evaluation Program (PREP) nurseries since there was no commercial field reported with BPB disease in 2014. In 2014, 200 Uniform Regional Rice Nursery (URRN) and 90 ARPT entries were planted as hill plots interspaced with Jupiter and Bengal, the control checks. Entries were planted in two bays, one to serve as unsprayed check. One hundred twenty-nine entries rated resistant (R) and moderately resistant (MR) from field tests in 2012 and 2013. They were planted manually according to their approximate heading date so that everything could be inoculated under similar field conditions. Only 71 of these entries including Bengal and Jupiter had similar growth stages. These entries were transplanted and taken to the greenhouse for inoculation. Due to failure in symptom development, they were then kept in dew chambers for 48 h. To evaluate both the field and greenhouse nurseries, a 0 to 9 disease scoring scale was used where 0 showed no disease and 9, severe disease symptoms to BPB. Of 200 entries from URRN and ARPT tested in the field, 2 entries showed no symptom of the disease and 96 entries ranged from (R) to (MR) with a rating of 1 to 5. The remaining entries rated between 6 and 9 and were grouped as moderately susceptible (MS) and susceptible (S). Of the 71 entries inoculated in the greenhouse, 23 entries showed an S reaction that shifted from R/MR to MS/S with 48-h dew treatment. Bengal rated 8 under both environments while Jupiter rated 5 in the field and 6 in the greenhouse after the dew

treatment. The methods of spray inoculation, needle injection, soil inoculation with a bacterial suspension and vacuum infiltration of the bacterium into seeds were tested in 2014 using 2 to 4 cultivars. None of these inoculation methods were definitive enough to separate relative resistance among the entries tested. Repeated tests on detached leaf laboratory inoculations resulted in erratic data varying with plant age and leaf blade shape, size, and age. When spray, brush, and needle inoculations were compared on the susceptible variety CL151 at the adult growth stage in a greenhouse, spray inoculation rendered uniform panicle infection. Ten entries that rated R and MR in 2014 field tests were spray-inoculated in the greenhouse. Most of these entries appeared more resistant than Jupiter. These will be tested further at different growth stages.

INTRODUCTION

Bacterial panicle blight (BPB) of rice has been observed for many years in Arkansas and other southern rice-producing areas of the United States as a disorder of unknown cause. The disease was not considered a major problem until severe damage occurred on Bengal in the mid-1990s. Reseachers at Louisiana State University (1996-1997) discovered that *Burkholderia glumae* (formerly known as *Pseudomonas glumae*) was the major biotic agent causing BPB disease of rice. This disease has been increasing in rice production fields in Arkansas and other southern rice-producing states since 1995. It was so severe in 2010 and 2011 that it caused up to 60% yield loss in susceptible varieties (Cartwright, pers. comm.). Although *B. glumae* is the major species of bacteria frequently isolated from symptomatic rice panicles, the disease can be caused by more than one species of bacteria with different and/or overlapping habits. For instance, *B. glumae* is mainly seedborne while *B. gladioli* appears to be seedborne as well as residue-borne. This complexity of the bacterial species and their habits could contribute to the difficulty in managing BPB disease.

A few cultural methods were proved to reduce the disease. Fields having received less applied nitrogen had reduced BPB incidence. Data from 2012, 2013, and 2014 field tests showed that water stress (shortage) reduced the BPB disease but greatly affected grain yield. A study just completed on planting dates suggested that March- and April-planted rice may have fewer BPB symptoms than late-May planted rice. Cultural management works best in cultivars with some level of resistance (Wamishe et al., 2014).

The disease seems to be favored by extended night temperature during the summer season. Dew also appears to play a substantial role in symptom onset and disease progress; however, the roles of other weather factors that encourage the bacterial activity remain unclear. In 2012, the summer was hot and dry and in 2013 and 2014 wet and cold. In the past three years, BPB disease in Arkansas commercial fields went from minimal to none. During epidemic years, fields cropped to continuous rice appeared to have more severe disease symptoms. Bacterial panicle blight disease occurrence is unpredictable. There is not sufficient information on the effect of crop rotation, the extent the bacterial survival in soil or on crop residues, and unknown weather factors. Therefore, the disease cycle for BPB has not been fully understood yet.

Chemical control options used in Asia have not been registered for uses in the U.S. Currently, registered fungicides used on rice do not have activity on bacterial panicle blight. Development of antibiotic resistance in Asia to a product known as Oxolinic acid (Starner) has raised concern about getting this chemical registered in U.S. Bacterial panicle blight management thus largely relies on use of resistant varieties. Therefore, the objectives of this study were to (1) understand the biology of the bacteria that cause BPB; (2) develop suitable methods for screening and selecting resistant germplasm in the field, greenhouse, and laboratory; 3) identify rice lines with reliable genetic resistance for use in breeding programs.

PROCEDURES

Isolating and purifying *B.glumae* from symptomatic kernels of rice florets continued in 2014 as in the past three years. Sample collections in 2014 were from the Arkansas Rice Performance Trials (ARPT) and Producer Rice Evaluation Program (PREP) across the state. CCNT agar medium was used to isolate *B. glumae*. The CCNT agar is a partial selective medium containing 2 g of yeast extract, 1 g of polypepton, 4 g of inositol, 10 mg of cetrimide, 10 mg of chloramphenicol, 1 mg of novobiocin, 100 mg of chlorotharonil, and 18 g of agar in 1000 mL of distilled water, and adjusted to pH 4.8 (Kawaradani et al., 2000). Isolates that produced a yellow pigment in CCNT agar medium were preserved to be tested for hypersensitivity on wild tobacco (*Nicotania rustica*) and pathogenicity on susceptible rice seedlings. Other isolates which grew well on CCNT medium but did not produce a yellow pigment were also preserved for future attempts to investigate a bio-control option for BPB disease. Pure isolates from the past three years stored at -80 °C in 25% glycerol were used in 2014 for field, greenhouse, and laboratory inoculation. A mixture of four isolates (#3, 28, 32, and 33) was combined equally to create a stock bacterial suspension. Before inoculation, the bacteria were cultured on King's B medium to increase their numbers.

To screen rice germplasm for BPB resistance, 200 Uniform Regional Rice Nursery (URRN) and 90 ARPT entries were planted in hill plots interspaced with Jupiter and Bengal at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Jupiter and Bengal were used as reference checks for moderately resistant and susceptible disease reactions. A separate bay was planted with each entry to serve as a non-inoculated control. The rice entries were inoculated between boot-split to flowering growth stage. Inoculation on each entry was applied twice in an interval of 4 to 5 days. Disease data were recorded three weeks after the last inoculation using a 0 to 9 scale, where 0 is no disease and 9 is severe disease. In addition to the 2014 URRN and ARPT entries, 129 entries that rated R and MR in the field evaluations of 2012 and 2013 were planted according to their approximate heading date with the goal of inoculating all plants under similar field conditions. Of 129 entries, 69 that reached similar growth stage were transplanted and inoculated in a greenhouse environment. Rice varieties Bengal and Jupiter were also transplanted and treated the same to serve as reference cultivars for disease scoring. A similar procedure to the field was followed in the greenhouse with the 69 entries and checks The rice plants in pots were inoculated twice in a four-day interval and placed on the greenhouse floor to reduce the effect of air movement by the fans. Due to failure in symptom development a week from first inoculation, plants were transferred to dew chambers and kept for 48 h. Limited capacity of the dew chambers, allowed only 36 entries to be placed in the dew chamber 4 days after the second inoculation, and the remaining 33 entries were placed in the chamber 7 days after the second inoculation. Disease data were recorded three weeks after the 2nd inoculation using a 0 to 9 scale. Inoculum for the field and greenhouse was prepared by growing *B. glumae* on petri dishes of King's B medium, a non-selective medium and incubated at 39 °C. A 24- to 48-h old *B. glumae* culture was washed with 10 mL of distilled sterile water and mixed in 1.5 liters of chlorine-free pure water. The solution was slowly stirred using a magnetic mixer for 30 min before using a backpack sprayer (Solo, Newport News, Va.) to apply a bacterial suspension of approximately 10^6 to 10^8 cfu/mL (colony forming units/mL) following the procedure adopted from LSU (Groth, pers. comm.).

Greenhouse seedling and laboratory detached-leaf inoculations continued in 2014. The main purpose was to search for a seedling inoculation method that would separate rice cultivars in their response to BPB disease. Spraying, needle injection, soil inoculation with a bacterial suspension, and vacuum infiltration of the bacterium into seeds were tested. In search of a better greenhouse inoculation method, spray and brush inoculation on panicles and needle inoculations on culms were compared using CL151, another known susceptible variety to BPB. To provide good coverage, 2 mL of bacterial suspension of ~10^6 to 10^8 cfu/mL were sprayed using a Badger 250-2 basic spray gun. For needle inoculation 0.5 mL of the bacterial suspension was carefully injected using a BD 31 gauge Ultra-FineTM Needle Insulin Syringe at vegetative stages 9 and 10 (flag leaf minus 3 and 4; Counce et al., 2000) and in the boot through the collar of the flag leaf. Both spray and needle inoculated plants were dew treated for 48 h immediately after inoculation. For brush inoculation, 0.5 mL of the bacterial suspension was used to dip a camel hair brush (size 0.5 inch). The head was then touched upwards on two sides with a wet brush immersed in bacterial suspension. After inoculation, the head was covered with a wet sandwich Ziploc bag to maintain humidity and placed under the greenhouse bench. Distilled sterile water was applied similarly for the checks. Ziploc bags were used anticipating a similar effect to the dew chambers.

Based on information obtained from the above inoculation methods, 10 entries were selected that rated resistant and moderately resistant in the 2014 URRN/ARPT field test. They were grown in a greenhouse and spray-inoculated twice in an interval of 3 to 5 days as described above. After each inoculation a 48-h dew treatment was maintained. Bengal and Jupiter were used for reference to BPB disease reactions.

Based on the 2013 and 2014 field and greenhouse data, 13 selected rice entries that were rated R/MR were planted in a greenhouse for molecular study. Three susceptible cultivars were included as control checks. Plants were spray-inoculated and maintained as described above. Head and leaf samples were collected with three time intervals.

RESULTS AND DISCUSSION

Twelve isolates were purified on CCNT, a semi-selective medium, and are currently being tested for hypersensitivity on wild tobacco leaves. These isolates will be used to inoculate rice in a greenhouse for bioassay studies and to evaluate germplasm for resistance in the field as needed. No commercial rice field was reported to have BPB disease in 2014 in Arkansas. Therefore, all the 12 isolates were purified from ARPT and PREP across the state.

Of the 200 entries from the 2014 URRN tested in the field, 2 entries showed no symptom of the disease and 48 entries ranged from resistant to moderately resistant with a rating of 1 to 5. The remaining URRN entries rated between 6 and 9 and were grouped as moderately susceptible to very susceptible; Fig. 1, Table 1). Of 90 ARPT entries, 50 ranged from resistant to moderately resistant (Table 1, Fig. 2). The cutoff point between moderately resistant and moderately susceptible was based on the reaction of the known moderately resistant Jupiter and the susceptible variety Bengal that rated 5 and 8, respectively. The rice entries in the non-inoculated bay showed no symptom of BPB. However, a few plants from the filler Bengal plots had BPB symptoms likely derived from natural infected seeds. Bengal filler plots in the inoculated bay had more BPB disease which likely was caused from naturally infected seeds and bacterial drift from test entry inoculations. Changes from row plots to hill plots were made to minimize border effect and maintain uniform heading within each rice entry. Inoculations were made over a period of five weeks and during that time weather factors could have varied from sunny to cloudy or rainy days. Each entry was inoculated twice in an interval of 4 to 5 days to cover main panicle and tillers. Due to difficulty of inoculating all entries at the same time and under similar weather conditions, change in response of the rice cultivars to the pathogen may vary making comparisons challenging.

Of 129 entries re-planted from 2012-2013 URRN/ARPT, only 71 that reached a similar growth stage were transplanted and inoculated under a greenhouse environment. Of these, 23, not including the checks, showed a susceptible reaction shifting from R/MR to MS/S with 48-h dew treatment (data not shown). This situation indicated the importance of dew treatment in the onset of the bacterial activity and symptom development after inoculation. The inoculated bacteria stayed inactive until the dew treatment was applied. Most entries were kept close to each other. The smaller growth chambers had the entries very close together which resulted in a more severe infection compared to those placed well apart in a bigger growth chamber. Only 53% of entries planted according to their heading date were ready for inoculation under similar conditions.

None of the greenhouse seedling inoculations were definitive enough to separate relative resistance among the entries tested. Data from detached leaf laboratory inoculations were also inconsistent as plant age and leaf blades varied. When spray, brush, and needle inoculation methods were compared on adult plants of CL151 in the greenhouse, spray inoculation appeared better to render uniform panicle infection. Only a few florets showed BPB symptoms with needle-boot inoculation through the collar of the flag leaf. Brush inoculation was not as effective as spray inoculation. Needle inoculation at vegetative stages 9 and 10 (flag leaf minus 3 and 4) produced typical lesions on the sheath and culm with severe floret infection. All were dew treated for 48 h after inoculation. Based on information obtained from these inoculation methods, 10 selected entries that rated resistant and moderately resistant in the field of 2014 URRN and ARPT were spray-inoculated twice in an interval of 3 to 5 days. Due to variability within and between entries, multiple inoculations were made between 15 January and 18 February 2015. Each time after inoculation, a 48-h dew treatment was provided. Bengal and Jupiter were included as control checks. All entries showed higher levels of resistance compared to Jupiter (data not shown). These entries are currently being grown in a greenhouse to be tested for resistance at different growth stages. From greenhouse and laboratory tests on seedling or detached leaves, adult-plant evaluation methods appeared to be more consistent in cultivar response to the pathogen. Time interval sample collections on the 13 rice cultivars and the three susceptible checks for molecular study are underway.

SIGNIFICANCE OF FINDINGS

The major objective of this project is to identify practical diagnostic methods of screening for resistance and monitoring rice bacterial panicle blight disease. Despite the method for resistance, gene identification is still premature; our findings thus far should enable the identification of resistant rice germplasm for breeders to use to control BPB. Development of a better toolbox to screen genetic resistance remains to be an important priority in crop protection. Ultimately, rice resistance to BPB would provide long-term control in years of increased disease pressure and thus improve yields.

ACKNOWLEDGMENTS

The support of extension rice pathology research by the Arkansas Rice Research and Promotion Board is highly appreciated. We are grateful to Rick Cartwright of University of Arkansas System Division of Agriculture for his technical help, Don Groth of Louisiana State University, and C. Wilson, K. Moldenhauer and J. Hardke of University of Arkansas for their collaboration. We appreciate USDA Agricultural Research Service Dale Bumpers National Rice Research Center for continued cooperation.

LITERATURE CITED

Counce, P.A., T.C. Keisling, and A.J. Mitchell. 2000. A uniform objective and adaptive system for expressing rice development. Crop Science. 40:436-443.

Kawaradani, M., K. Okada, and S. Kusakari. 2000. New selective medium for isolation of *Burkholderia glumae* from rice seeds. J. Gen. Plant Pathol. 66:234-237.

Wamishe, Y., T. Gebremariam, C. Kelsey, S. Belmar, and S.D. McCarty. 2014. Development of short-term management options for rice bacterial panicle blight disease. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:133-142. Fayetteville, Ark.

Table 1. Resistant and moderately resistant entries from ARPT (Arkansas Rice Performance Trials) and URRN (Uniform Regional Rice Nursery) to bacterial panicle blight (BPB) disease of rice rated after artificial inoculation at Rice Research and Extension Center near Stuttgart, Ark.

URRN 2014 R-MR[a] for BPB			ARPT 2014 R-MR[a] for BPB		
Entry #	Accession	BPB Score[b]	Entry #	Accession	BPB Score[b]
71	RU1102071[c]	0	42	RU1201047[c]	1
142	RU1401142	0	44	RU1401145	1
47	RU1201047[c]	1	19	RU1102071[c]	2
7	RU1401007[c]	2	40	RU1201136[c]	2
76	RU1201136[c]	2	27	RU1401007[c]	2
148	RU1401148[c]	2	45	RU1401148[c]	2
160	TAGGART[c]	2	81	RU1401173[c]	2
173	RU1401173[c]	2	84	RU1401182[c]	2
182	RU1401182[c]	2	64	STG09L-22-058	2
13	RU1301102[c]	3	3	TAGGART[c]	2
20	MERMENTAU[c]	3	7	MERMENTAU[c]	3
38	WELLS[c]	3	2	ROYJ[c]	3
79	ROYJ[c]	3	61	RU1301102[c]	3
176	RU1401176[c]	3	82	RU1401176[c]	3
179	RU1401179[c]	3	83	RU1401179[c]	3
194	RU1404194	3	58	STG08P-09-112	3
2	RU1402002	4	57	STG11L-26-175	3
4	RU1301087[c]	4	4	WELLS[c]	3
11	RU1402011	4	59	RU1001161	4
24	RU1201024[c]	4	36	RU1201024[c]	4
31	RU1402031	4	53	RU1301087[c]	4
32	RU1303138	4	26	RU1401070[c]	4
64	JES	4	34	RU1401081[c]	4
70	RU1401070[c]	4	67	RU1401121[c]	4
81	RU1401081[c]	4	46	RU1401188[c]	4
121	RU1401121[c]	4	51	STG06L-34-055	4
169	RU1203169	4	49	STG08L-59-103	4
178	RU1405178	4	62	STG10P-23-028	4
188	RU1401188[c]	4	63	STG11F3-02-115	4
21	RU1301021[c]	5	30	STG11IMI-06-228	4
29	RU0803153	5	88	STG11P-04-196	4
30	RU1401030[c]	5	89	STG12L-28-130	4
33	RU1204196	5	87	STG12L-30-127	4
41	RU1201102[c]	5	21	2319-13001	5
46	RU1303153	5	14	CL JAZZMAN[c]	5
75	RU0903190	5	12	CL152[c]	5
87	RU1401087[c]	5	15	RTCLXL729	5
99	RU1401099[c]	5	16	RTCLXL745	5
113	RU1003113	5	17	RTXL723	5
120	CL JAZZMAN[c]	5	18	RTXL753	5
126	RU1403126	5	24	RU1201102[c]	5
147	RU1203147	5	23	RU1201151[c]	5
151	RU1201151[c]	5	69	RU1301021[c]	5
161	RU1401161[c]	5	65	RU1401030[c]	5
166	RU1403166	5	28	RU1401087[c]	5
200	CL152[c]	5	39	RU1401099[c]	5

continued

Table 1. Continued.

URRN 2014 R-MR[a] for BPB			ARPT 2014 R-MR[a] for BPB		
Entry #	Accession	BPB Score[b]	Entry #	Accession	BPB Score[b]
			86	RU1401105	5
			29	RU1401161[c]	5
			31	STG12IMI-05-161	5
	JUPITER (check)	5		JUPITER (check)	5
	BENGAL (check)	8		BENGAL (check)	8

[a] Disease rating scale where 0 = no disease, 9 = severe BPB disease.
[b] R = resistant, MR = moderately resistant.
[c] Entries present in both ARPT and URRN.

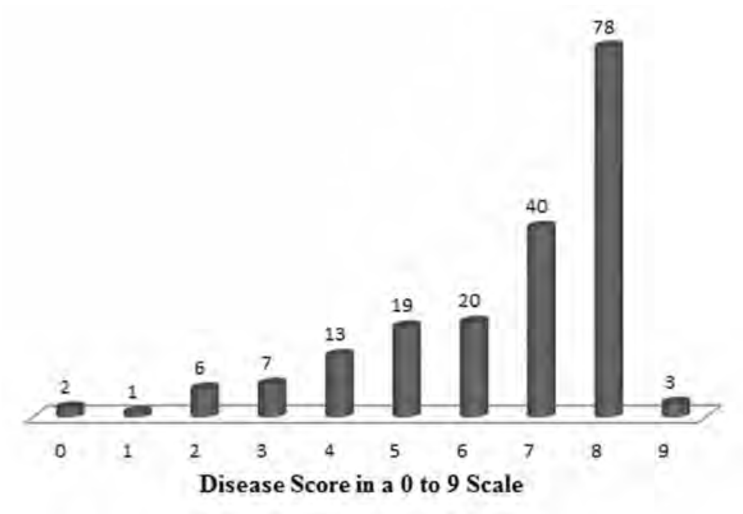


Fig. 1. Field bacterial panicle blight disease score of the 2014 Uniform Regional Rice Nursery (URRN) using artificial spray inoculation.

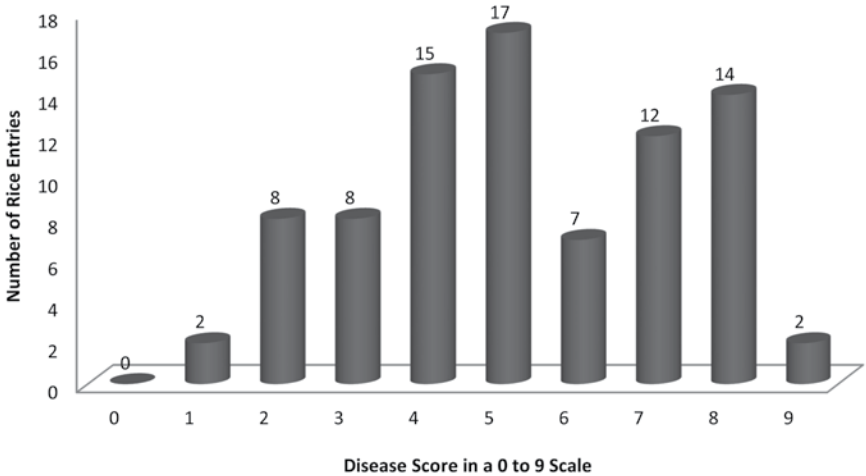


Fig. 2. Field bacterial panicle blight disease score of the 2014 Arkansas Rice Performance Trials (ARPT) using artificial spray inoculation.

Studies on Cultural Management Options for Rice Bacterial Panicle Blight Disease

Y.A. Wamishe, T. Gebremariam, S. Belmar, C. Kelsey, and T. Mulaw

ABSTRACT

To evaluate the effects of planting date, water stress, nitrogen fertilizer level, and seeding rate on bacterial panicle blight (BPB) disease of rice, field trials were conducted in 2014 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Similar to the past two years, seeds were artificially inoculated to establish a uniform infection. Late-planted plots had significantly higher BPB disease incidence on both Bengal (susceptible variety) and Jupiter (moderately resistant variety) resulting in yield and milling quality losses. Water shortage (stress) showed more of a negative effect on yield than BPB disease for both inoculated and non-inoculated plots. Although BPB disease incidence was greater in plots with a permanent flood, the grain yields were still higher than the plots with intermittent flooding. Total mean water provided during the 2014 season for the intermittent treatment was 42% less than for the flooded plots. Unlike last year, seeding rate showed a treatment effect on disease incidence both in Bengal and Jupiter. Mean disease incidence in Bengal treated with 220 lb nitrogen (N)/acre was nearly 1.5 times higher than with the 150 lb N/acre rate. The two fertility levels showed no substantial differences in grain yield or milling quality.

INTRODUCTION

Bacterial panicle blight (BPB) has been observed in rice production fields of Arkansas and other southern states with an increasing frequency from 1995 to 2011 (Cartwright, pers. comm.). The disease is primarily seedborne and seems to favor hot summer nights. In 2010 and 2011, BPB was severe and caused up to 60% yield loss under environmental conditions favorable for the pathogen development and reproduction (Cartwright, pers. comm.). Panicle symptoms typically develop late in the season, which makes predicting disease occurrence difficult. Infected panicles mostly have blighted florets which first appear white to light gray with a dark-brown margin on the basal third of the tissue. Later, these florets turn straw-colored and may further darken toward the end of the season with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. There are no chemical options registered in the U.S. to protect or salvage the crop from the disease. This disease is sporadic which in part could be due to changes in weather and environmental conditions along with multiple causal agents that may survive in seeds, soil, or crop residues. Unlike the historic years of 2010 and 2011, BPB pressure was relatively low in 2012 and 2013. There was no report of BPB in commercial rice fields of Arkansas in 2014. The rice season of 2012 was hot and dry. In 2014, it was wetter and cooler than 2013. Both conditions appeared unfavorable for natural prevalence of the disease. Most conventional and current rice varieties are susceptible to the disease. This study presents cultural management options that may be used solely or in combination with other options to reduce BPB of rice until resistance is identified and incorporated into high yielding and adapted cultivars.

PROCEDURES

Land Preparation and Planting

In 2014, the test area with both fallow and land previously cropped to rice was tilled and prepared in the early spring. A preplant fertilizer of Triple Super Phosphate (65 lb/acre), potassium chloride (100 lb/acre), and CoZinco (30 lb/acre) was applied. A burn down application of Gramoxone Inteon was applied to kill weeds or off-type rice. The area was then rototilled to loosen the soil and ensure a good seed bed. Planting was done with a Hege 1000 seed drill set to plant 8 rows on 8-inch row spacing with approximately 1-inch seed depth. The plots were approximately 5 ft × 14 ft. After planting, the plots were rolled to ensure good soil to seed contact and to prevent moisture loss.

Evaluation of the Effects of Planting Date on Rice Bacterial Panicle Blight Disease

This was the third year to test if planting dates affect BPB disease severity under Arkansas conditions. Although more than one species of *Burkholderia* species are involved in causing rice BPB disease, tests were carried out using only *B. glumae* because it was more frequently isolated from infected kernels in Arkansas. To obtain uniformly infected seeds and to ensure the survival of the bacteria until cotyledon emergence, an artificial seed inoculation method was utilized. A 2- to 4-day-old culture of *B. glumae* was grown on non-selective King's B medium at 104 °F. The culture was then washed from a petri dish with sterile water to obtain a one mL suspension with approximately

10^6 to 10^9 colony forming units (cfu)/mL. The bacterial suspension was mixed with 4 mL salt-sugar buffer (1 g yeast extract, 2.36 g NaCl, 3.4 g sucrose per liter of distilled water; Streeter, 2007). The mixture was infiltrated into 40 g of Bengal or Jupiter rice seed by applying a vacuum (25 inch Hg vacuum) for 5 min in a loosely sealed mason jar followed by restoring atmospheric pressure with the removal of the lid. The vacuuming process was repeated a second time. Seeds were then covered with enough talc (powder) to absorb excess liquid and ease planting. The talc shield also served as a buffer between soil and seeds until germination. After emergence, samples of cotyledons were tested for the presence of *B. glumae* on partially selective medium designated CCNT (Kawaradani et al., 2000). The CCNT medium contained 2 g of yeast extract, 1 g of polypepton, 4 g of inositol, 10 mg of cetrimide, 10 mg of chloramphenicol, 1 mg of novobiocin, 100 mg of chlorotharonil, and 18 g of agar in 1000 mL of distilled water, and adjusted to pH 4.8. In 2014, artificially inoculated seeds of Bengal (susceptible variety) and Jupiter (moderately resistant variety) were planted at the recommended seeding rate of 88 lb/acre. The first and second plantings were done on 21 March and 22 April, respectively, very close to the past two years of planting. All treatments were maintained similar to 2012 and 2013. Panicles with greater than 50% infection per plot were counted. Yield and quality data were also collected and analyzed.

Evaluation of Water Stress on Bacterial Panicle Blight Disease

Year 2014 was the third test season to determine if water stress (shortage) affects BPB disease severity. Rice varieties of Bengal and Jupiter were planted at the rate of 88 lb/acre on 22 May, six days behind the previous year. Half of the plots were planted with bacteria-inoculated seed and the other half with non-inoculated seeds. All treatments were replicated four times each in 5 ft × 14 ft plots. In 2013, the intermittent flooding was modified with intermittent flushing and a moderately resistant variety, Jupiter, was also included in the test. In 2014, the intermittent flushing plots were allowed to dry down to a soil moisture content of approximately 60% before being re-wetted four times over the season rather than six times as needed in 2013. Fewer flushings were due to frequent rain that kept the plots above the set soil moisture level. Soil moisture was monitored and recorded by soil moisture sensors (Irrometer Co., Riverside, Calif.) placed at depths of 2 and 4 inch. Water usage was recorded with flow meters (McCrometer, Hemet, Calif.) installed in each of the four bays of the test. The permanent flood bays remained flooded throughout the growing season until drained for harvest.

Effects of Excessive Nitrogen Fertilizer on Rice Bacterial Panicle Blight

This was the third year for this study. In 2014, the test was repeated as in 2013 and plots were planted on 21 May, a week ahead of the previous year. Unlike 2012, fertility and seeding rate treatments were separated and the difference between fertility levels was changed from 150 and 180 lb N/acre in 2012 to 150 and 220 lb N/acre in 2013. Moreover, planting date was modified from April to late May to encourage disease development and the experimental design was changed from a split plot to a completely randomized design. Bacteria-inoculated seeds of Bengal were planted at a recommended seeding rate at 88 lb/acre

Evaluation of Effect of Seeding Rate on Bacterial Panicle Blight Disease

In 2014, the experiment was repeated as in 2013. Planting was done later on 21 May. Bacteria-inoculated seeds of Bengal were planted at a recommended seeding rate of 88 lb/acre and a higher seeding rate at 176 lb/acre. Land preparation and input application were maintained as in 2013.

RESULTS AND DISCUSSION

In 2014, plots established with artificially inoculated seeds showed BPB severity lower than in 2013 and much less than 2012. The spring and summer in 2014 were cooler with frequent rain compared to the 2013 season which appeared unfavorable for BPB disease development. However, disease incidence was enough to compare treatment effects in all the four cultural practices tested. Disease incidence was higher in the third planting (late May) compared to the March- (first) and April- (second) planted plots. The trend for BPB disease incidence in 2014 was in agreement with results in the past two years. The mean disease severity on third planting date from Bengal plots in 2014 was nearly 25 and 8 times higher than the first and second planting dates, respectively. Mean disease incidence in Bengal was nearly 12 times higher than in Jupiter. (Fig. 1). Bacterial panicle blight disease severity was relatively low across planting dates for the moderately resistant variety Jupiter. Plots of the third planting had the lowest total yield and head rice yield. There was no significant difference in total percent milling between first and second planting dates while the third planting was lower. Although the extent of the bird damage was not measured, grain yield in March-planted plots was highly affected by bird feeding before emergence and after heading. Yield comparisons were made between April-planted and May-planted plots. From the May planting, Bengal showed a 35% yield loss when compared to the yield of the April planting. Likewise, Jupiter showed a 26% yield loss. In both varieties, the yield losses were quite substantial although the loss may not be fully accounted for by the disease severity (data not shown). Late planting itself affects yield adversely.

Historically, early planting is generally encouraged to allow adequate time for plant development and grain fill and also to escape some rice diseases such as blast. This study indicated March to April planting dates minimized BPB disease incidence resulting in lower effects on yield and grain quality. Observations in previous years showed BPB disease of rice more severe with high temperatures, particularly extended nighttime air temperatures. It is not yet well understood at which stage of the crop that temperature plays the greatest role and what other factors are involved. Artificial foliage spray inoculation in another study was effective between boot split and flowering. In our germplasm evaluation studies, the flowering stage of the crop appeared more susceptible to infection by *B. glumae* than the boot split or even earlier. High humidity together with prolonged high night temperatures seemed to be a key factor in increased disease severity. Favorable temperature and humidity at earlier crop stages up until boot or boot split may allow the survival of the bacteria in the plant possibly as an epiphyte if the inoculum source is assumed to be seed or soil. These bacteria then move up the crop canopy and eventually become established in panicle florets. Inoculated seeds with *B. glumae*, when planted in the field, produced BPB diseased plants. In our preliminary study, when plant tissue samples were examined using CCNT media and polymerase chain reaction (PCR), root and leaf samples were found negative. These samples, free of *B. glumae*, suggest root and leaf tissue are non-preferential habitats for the pathogen. There was a distinct agreement with both the culture and PCR findings that the sheath, culm, and panicle florets are possible habitats for the bacteria (data not shown). Under laboratory conditions, *B. glumae* grows well on CCNT or King's B media at temperatures between 98 °F and 104 °F. These bacteria also grow at room temperature but at a slower rate. In 2012, Bengal and Jupiter took nearly three months to reach boot stage. Stuttgart weather data indicated the average air maximums from 78.2 °F to 88.4 °F and the average minimums from 55.4 °F to 68.6 °F for the months of April to June, respectively. The average maximum for July and August was 93.6 °F and 87.1 °F while the minimum 74.5 °F and 70.9 °F, respectively. Average minimum soil temperatures for July and August were 81 °F and 77.7 °F. Soil temperature may play a role in raising the humidity under the canopy for a favorable microenvironment for the bacteria. However, there is no report on the role of soil temperature on the survival or multiplication of the bacteria. In 2012, tropical storm Isaac helped with the spread of the bacteria within plots for the third planting by raising the disease incidence to near perfect across the plots. Nothing like that happened in 2013 and 2014 where the seasons were much wetter and cooler than 2012 with no noticeable storm. Rice planted in the third week of March (first planting date), emerged in about a month while the second planting took about two weeks to emerge. Seeds in all three planting dates were inoculated similarly and the lower disease incidence in 2013 and 2014 cannot be attributed to the absence of inoculum to start with. Although the seeds planted in May (third planting) emerged in seven days, most of the inoculum applied to the seed appeared washed away. Despite the low disease incidence in 2013 and 2014, the disease data showed a trend similar to 2012 for both varieties indicating more BPB disease with a later planting.

Data from water stress tests showed BPB disease incidence twice as high in continuous flooded plots compared to intermittent flooded Bengal plots (Fig. 2). This disease trend was similar to what was observed in the previous two years. Jupiter had much less disease than Bengal. Continuous or intermittent flooding appeared not to affect Jupiter (the moderately resistant variety). The grain yield of both Bengal and Jupiter were greatly affected by late planting more than by the disease. However, the effect of water stress on yield was shown to be greater than the BPB disease. There was significant difference between inoculated and non-inoculated plots in BPB incidence resulting in no yield difference between the two. Milling quality of Jupiter was reduced more in the water stressed condition than for Bengal (data not shown). Total mean water provided in 2014 during the season for the intermittent treatment was 1.88 acre-inch or 42% less than that flooded at 3.23 acre-inch. Due to a cooler rice season with more frequent rain, the plots having intermittent flushing were re-wetted four times during the growing season compared to six times in 2013.

Planting the fertility test in 2014 was done eight days earlier than in 2013. Weather in 2014 offered a narrow window for planting. Bacterial panicle blight disease data from the fertility test showed a mean disease incidence at 220 lb N/acre to be 1.5 times higher than that of 150 lb N/acre which was close to the level of disease seen in 2013 for the Bengal plots (Fig. 3). Overall disease incidence in Jupiter plots was relatively low which confirmed the trend of the previous year. The two fertility levels showed no substantial differences in grain yield or milling quality for both varieties (data not shown). However, there were large grain yield differences between the two varieties. Bacterial panicle blight disease development from inoculated seed was low but it was enough to show a disease trend when nitrogen levels were at or above recommended rates.

Effect of seeding rate on BPB may vary with tillering the capacity of the cultivar. The denser the canopy the more BPB disease was observed. In the previous year, Bengal appeared to have more tillers than Jupiter. Seeding rate at 176 lb/acre increased BPB disease by 1.7 times for Bengal and 2.8 times for Jupiter compared to the recommended seeding rate of 88 lb/acre (Fig. 4). Susceptibility to the disease appeared to have more effect on BPB disease than the seeding rate. Grain yield and milling quality did not show large differences between treatments (data not shown).

SIGNIFICANCE OF FINDINGS

Bacterial panicle blight has been an important disease in Arkansas rice causing millions of dollars loss in the historic years of 2010 and 2011. With lack of resistance in current commercial rice cultivars and absence of chemical options, cultural management options are of immense advantage to rice producers to combat this yield robbing disease until cultivars with resistance are developed. Moreover, cultural management options integrated with some level of resistance in high yielding varieties would be very useful. While the development of resistant cultivars will offer the best long-term control, short-term disease management options need to be explored. The findings in these studies are consistent across the past three years.

ACKNOWLEDGMENTS

Special appreciation is extended to the Rice Research and Extension Board for providing funding and support for these projects; to Rick Cartwright of University of Arkansas System Division of Agriculture, and Don Groth of Louisiana State University for their technical help and Chris Henry of University of Arkansas for his assistance in irrigation.

LITERATURE CITED

Kawaradani, M., Okada, K., and Kusakari, S. 2000. New selective medium for isolation of *Burkholderia glumae* from riceseeds. J. Gen. Plant Pathol. 66:234-237.

Streeter, J.G. 2007. Factors affecting the survival of *Bradyrhizobium* applied in liquid cultures to soya bean [*Glycine max* (L.) Merr.] seeds. J. Appl. Microbiol. 103:1282-1290.

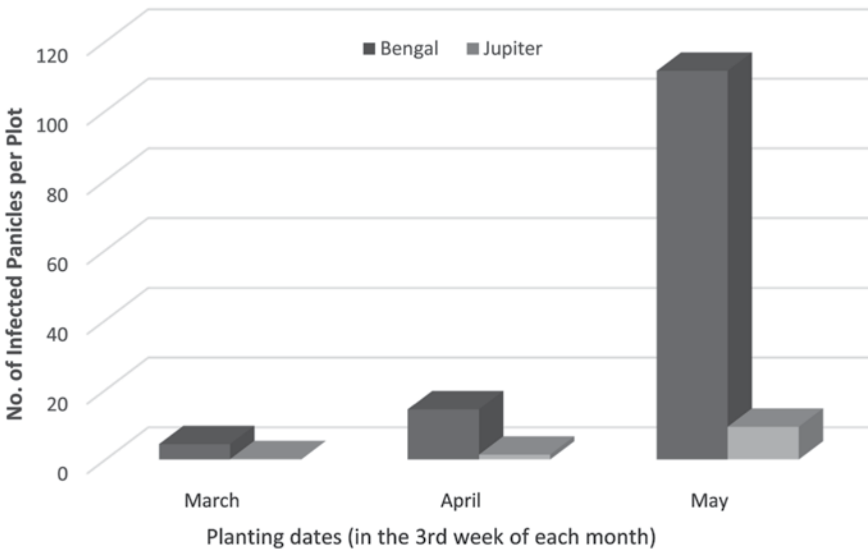


Fig. 1. Effect of planting dates on incidence of bacterial panicle blight in 2014 at α = 0.05 LSD = 12.6.

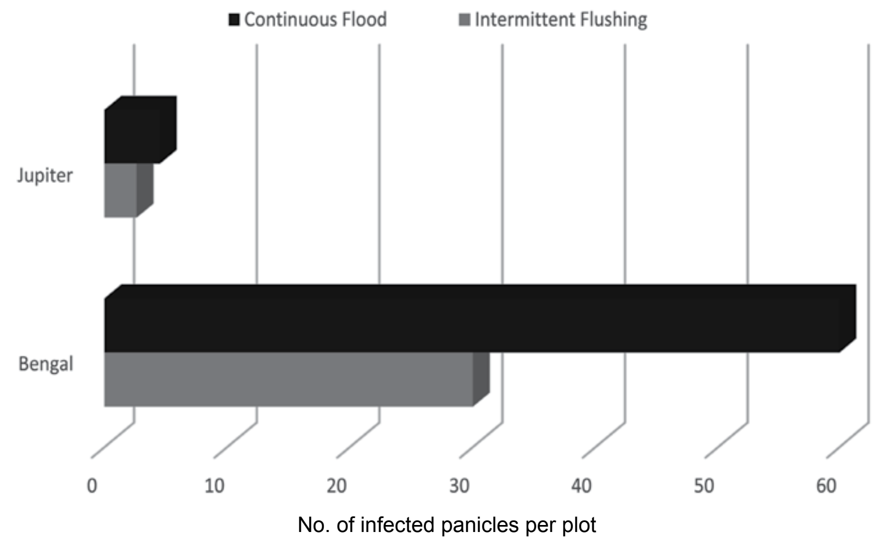


Fig. 2. Effect of water stress on BPB disease incidence in 2014 at α = 0.05 LSD = 11.3.

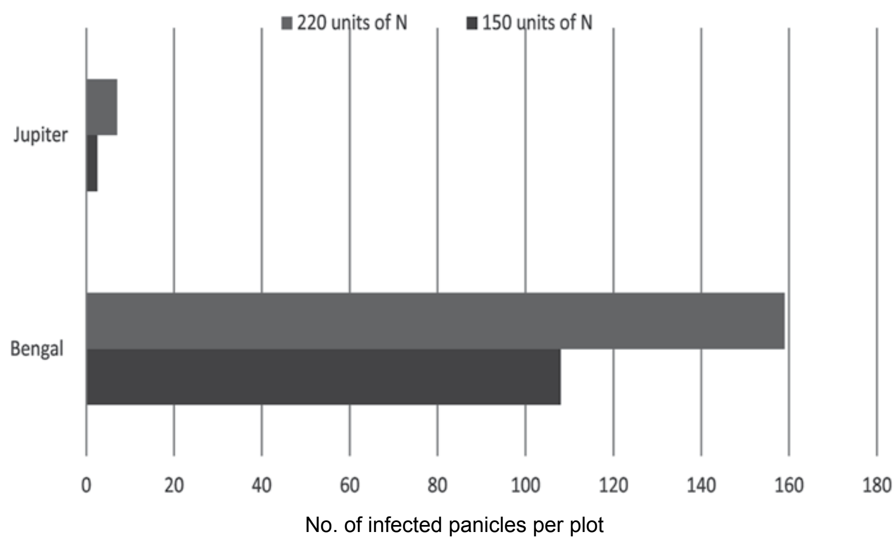
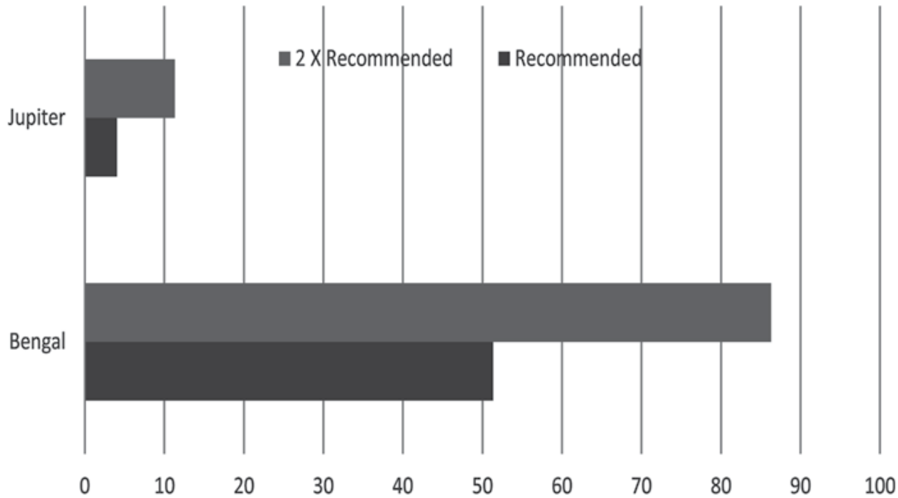


Fig. 3. Effect of nitrogen on bacterial panicle blight in 2014 at α = 0.05 LSD = 41.6.



No. of infected panicles per plot

Fig. 4. Effect of seeding rate on BPB incidence on Bengal and Jupiter in 2014 at α = 0.05 LSD = 16.1.

Stored-Product Insects Associated with On-Farm Storage Sites

T. McKay, M. Bowombe Toko, B. Hale, R. Hampton, and L. Starkus

ABSTRACT

A study was conducted from 2014 May to 2014 November on four on-farm rice storage facilities in northeast Arkansas to examine the temporal and spatial distribution of stored-product insects. The two most abundant beetles found at all locations were the warehouse beetle (*Trogoderma variabile*) and the lesser grain borer (*Rhyzopertha dominica*). Indianmeal moths (*Plodia interpunctella*) were also abundant. The red flour beetle (*Tribolium castaneum*) and cigarette beetle (*Lasioderma serricorne*) were present, but in lower numbers. Stored-product insects were abundant throughout the summer even when bins were empty.

INTRODUCTION

Bulk storage of rice is vulnerable to infestations of stored-product insects. One insect that is of importance to stored rice is the lesser grain borer, *Rhyzopertha dominica* (Potter, 1935). This pest exploits whole kernels of grain by feeding and developing fully to adult within the kernel. Other insects, such as cigarette beetles (*Lasioderma serricorne*), red flour beetles (*Tribolium castaneum*) and Indianmeal moths (*Plodia interpunctella*), typically feed on processed grains and broken kernels that have been damaged by primary feeders (USDA, 1980) such as the lesser grain borer. These insects have been associated with grain storage facilities. Warehouse beetles will survive on a variety of food sources including mixed animal feeds and processed grains such as polished rice (Partida and Strong, 1975). We investigated the occurrence of lesser grain borers, cigarette beetles, red flour beetles and Indianmeal moths associated with on-farm rice storage. By knowing when these insects occur, producers can incorporate this information into their integrated pest management (IPM) plans.

PROCEDURES

Insects were collected from 21 May through 30 November 2014 at four on-farm rice storage facilities in Craighead and Poinsett counties in northeast Arkansas. Location A stored a total of 75,000 bushels of rice in four bins. Bins ranged in size from 11,000 to 24,000 bushels each. Before rice was stored, all bins were treated with resmethrin. Rice was aerated using fans which were constantly running (except during heavy rains) until mid-November. Location B had five bins totaling 40,000 bushels with rice storage beginning in mid-September. Location C had a storage capacity of 137,500 bushels with five bins on the property. Location D had five bins totaling 50,000 bushels. Locations B-D were all treated with diatomaceous earth before rice was added to the bins. Locations B and C were also treated with malathion before rice was added. Locations B-D also used fans to aerate the rice and continuous aeration was used until temperatures dropped below 10 °C at night.

Five Delta glue traps (12 in. × 7 in.) (Scentry Biologicals Inc., Billings, Mont.) were hung on the exterior walls of the bins (~1.0 m to 1.5 m in height) and retrieved each week to collect trapped insects. Each Delta trap had a thin layer of glue (Bio-Quip Tangle-Trap®, Rancho Dominguez, Calif.) and was baited with four different Trécé® (Adair, Okla.) pheromone lures to attract the lesser grain borer, warehouse beetle, cigarette beetle, and Indianmeal moth. The lures were attached to the middle of each trap using a twist tie to ensure each pheromone would not dislodge. The lesser grain borer lures were replaced after four weeks in the field and the remaining lures were used for six consecutive weeks in the field. Ten Dome traps (Trécé, Inc., Adair, Okla.) were also placed at each facility to collect red flour beetles. Each Dome trap was baited with a red flour beetle pheromone lure which was replaced every eight weeks. To ensure Dome traps stayed in position, each trap was secured onto a metal holder (5.9 in. × 5.9 in.). Traps were collected each week until the mid-October when traps were collected every two weeks. Hourly temperatures were recorded at each facility using a HOBO® ProV2 (Onset Computer Corporation, Bourne, Mass.). Data loggers were retrieved every second week and taken back to the lab where the data were downloaded. All stored-product insects were identified to species.

RESULTS AND DISCUSSION

In 2014, the warehouse beetle and lesser grain borer were the two most common beetles associated with on-farm rice storage (Fig. 1). Indianmeal moths were also abundant (Fig. 1). Although all locations had warehouse beetles, Location D had the most warehouse beetles with 977 beetles collected (Fig. 2). Over 400 warehouse beetles were collected at Location A and smaller numbers of warehouse beetles were collected at the other two locations (Fig. 2). Warehouse beetles have been associated around grain facilities (Larson et al., 2008) and this beetle was the most common insect collected at a rice mill in northeast Arkansas (White, 2011). Location B had the most lesser grain borers collected with 523 individuals (Fig. 2). Indianmeal moths were also abundant but there were lower numbers of red flour beetles (Fig. 1). Interestingly, stored-product insects were present even when storage bins were empty (Fig. 3). Lesser grain borer numbers were highest at the beginning of the summer and decreased to a low on the 6 August. Lesser grain borer numbers had another peak on 13 August, decreased on 3 September and increased slightly after rice was placed in the bins. A high number of warehouse beetles were observed on 21 May, and peaked on 18 June. Numbers of warehouse beetles decreased in July, but a second peak occurred on 13 August. The populations of warehouse beetles decreased into the first week of September. However, there was a slight increase in warehouse beetles collected in the first week of September. There were a few Indianmeal moths collected in May and the populations increased in June, with a slight decrease on 23 July. Indianmeal moth numbers increased to a high of 382 individuals on 13 August (Fig. 3). The numbers decreased slightly on 3 September and then slightly increased again when rice was beginning to be loaded into the bins. Red flour beetles do not seem to be a common insect pest associated for on-farm rice storage bins in northeast Arkansas.

SIGNIFICANCE OF FINDINGS

This study provides information of the population dynamics of four important stored-product insects. These stored-product insects are present throughout the summer, and producers should be implementing IPM strategies even when rice is not being stored on premise. Research on various insect control strategies before rice is stored is needed.

ACKNOWLEDGMENTS

We would like to thank the Arkansas Rice Research and Promotion Board for funding this project. We also appreciate the rice producers who allowed us access to their rice storage facilities.

LITERATURE CITED

Larson, Z., B. Subramanyam, and T. Herrman. 2008. Stored-product insects associated with eight feed mills in the midwestern United States. J. Economic Entomology 101:998-1005.

Partida, G.J. and R.G. Strong. 1975. Comparative studies on the biologies of six species of Trogoderma: *T. variabile*. Annals Entomological Society of America 68:115-125.

Potter, C. 1935. The biology and distribution of *Rhyzopertha dominica* (Fab.). Trans. Royal Entomological Society of London 83:449-482.

USDA, 1980. Agricultural Handbook Number 500. U.S. Government Printing Office, Washington, D.C.

White, A. 2011. Population dynamics of stored-product insects at a rice mill in northeast Arkansas. M.S. Thesis, Arkansas State University, Jonesboro, Ark.

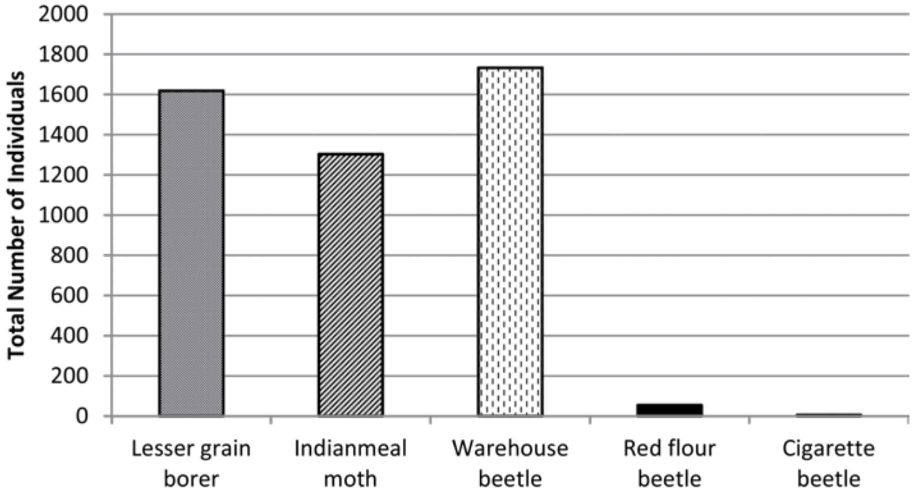


Fig. 1. Total number of stored-product insects collected using Delta traps and Dome traps between 21 May to 30 November 2014 from four on-farm storage facilities in northeast Arkansas.

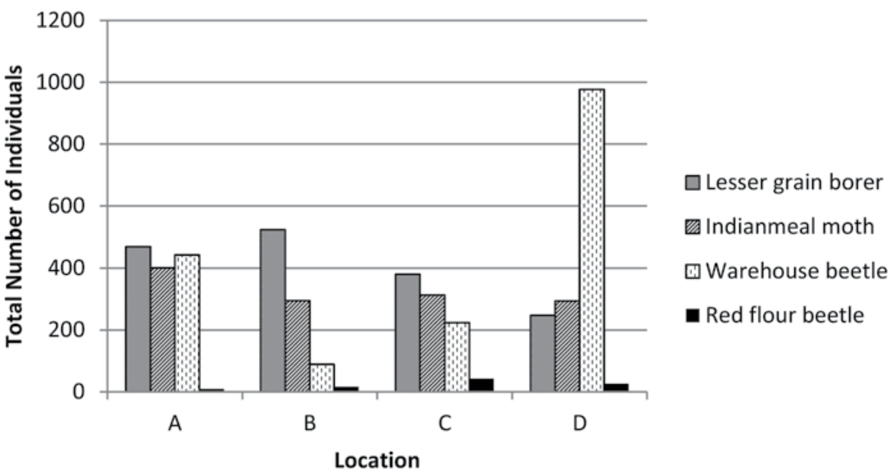


Fig. 2. Total number of lesser grain borer, warehouse beetle, Indianmeal moth, and red flour beetles collected from 21 May to 30 November 2014 from four on-farm rice storage sites.

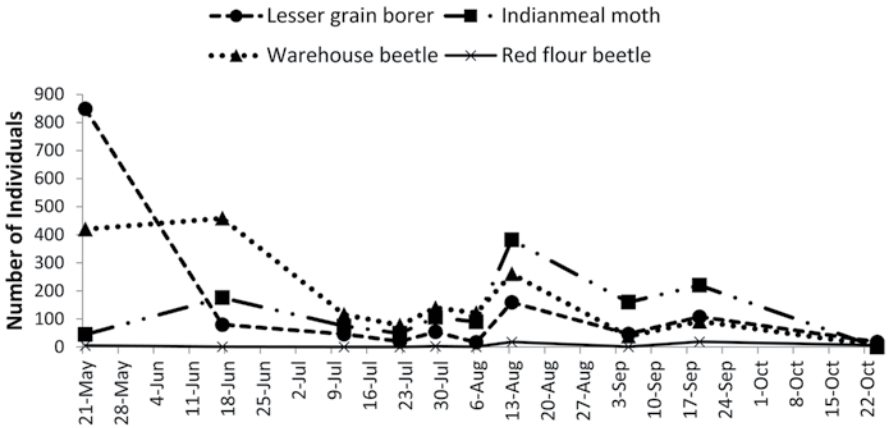


Fig. 3. Seasonal activity of the lesser grain borer, warehouse beetle, Indianmeal moth, and red flour beetles collected from 21 May to 30 November 2014 from four on-farm rice storage sites.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas 2011-2013

W.A. Plummer, G.M. Lorenz, N.M. Taillon, H.M. Chaney,
B.C. Thrash, D.L. Clarkson, M.E. Everett, and L.R. Orellana Jimenez

ABSTRACT

The rice stink bug, *Oebalus pugnax*, has been of concern to Arkansas rice producers for many years. Its feeding causes yield reduction and decrease of rice quality or pecky rice. Studies were conducted over a three year period to determine the efficacy of selected insecticides for control of this pest. Our studies indicated that new insecticides may have potential value for control of stink bugs in rice. Also, when insect populations are high, multiple insecticide applications may be required to reduce numbers below University of Arkansas System Division of Agriculture's Cooperative Extension Service recommended thresholds.

INTRODUCTION

Rice stink bug is a common and important pest in Arkansas rice. In the spring, rice stink bugs feed and reproduce on a wide range of wild grasses. This enables the rice stink bug to reproduce and increase in numbers before cultivated host plants are available. Rice stink bugs normally do not occur in rice fields until heading has begun, but may occur earlier if heading wild grasses are present in or around field edges. Stink bug feeding on developing seeds causes several different types of damage to rice. Early feeding causes heads to blank or abort resulting in yield reduction. Later feeding during the milk-to-soft dough stage can cause kernel shrinkage or discoloration known as "pecky rice" which also results in yield reduction and deductions in quality or grade (Johnson et al., 2002).

PROCEDURES

In 2011, a trial was conducted in Lonoke County, Ark. (Perkins Farms). Foliar treatments included: Endigo ZC 5 oz; Endigo ZCX 5 oz; Karate Z 1.6 oz, 1.8 oz, and 2.56 oz; Centric 3.5 oz; Tenchu 9 oz; Declare 1.54 oz and 2.05 oz; and MustangMaxx 2.56 oz and 4 oz. Applications were made on 8 July and 20 July 2011. Insect ratings were taken six days after the first application and seven days after the second application.

In 2012, a trial was conducted in Lonoke County, Ark. (Moery Farms). Foliar treatments included: Endigo ZC at 5 oz; Endigo ZCX at 5 oz; Karate Z at 2.56 oz; Centric at 3.5 oz; and Tenchu 20 SG at 9 oz. Insecticide applications were made on 17 August and 4 September 2012. Insect ratings were taken four and seven days following the first application and seven days after the second application.

In 2013, a trial was located in Faulkner County, Ark. (Pearson Farms). Foliar treatments included: Declare 1.54 and 2.05 oz, Malathion 57% 2 pt, Karate Z 2.56 oz; CHA-3158 0.625 lb, 1.25 lb, and 2.5 lb; Endigo ZCX 5 oz; Tenchu 9 oz; Endigo ZCX 6 oz; and Centric 3.5 oz. Applications were made on 31 July 2013. Insect ratings were taken five and eight days after application.

Plot size for all trials was 12 ft × 25 ft in a randomized complete block design with four replications. Applications were made with a hand boom fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing, spray volume was 10 gal/acre at 40 psi. Insect density was determined by taking 10 sweeps per plot with a standard sweep net (15-in. diameter) and compared to the economic threshold of 5 rice stink bugs per 10 sweeps. Data was processed using Agriculture Research Manager Version 8 & 9, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

RESULTS AND DISCUSSION

In 2011, results indicated at six days after the first application (6DAT1) all treatments reduced rice stink bug populations below the untreated check (UTC) except for Declare 1.54 oz, MustangMaxx 2.65 oz, and Karate Z 1.6 oz (Table 1). Endigo ZCX 5 oz and Endigo ZC 5 oz reduced rice stink bugs below all other treatments but did not differ from Tenchu 9 oz, Centric 3.5 oz, Karate Z 2.56 oz, or Declare 2.05 oz. No treatments reduced rice stink bug numbers below economic threshold and a second application was made. At seven days after the second application (7DAT2), all treatments reduced populations below the UTC and economic threshold but treatments did not differ from each other.

In 2012, results indicated at four and seven days after the first application (4 & 7 DAT1) all treatments reduced rice stink bug numbers below the UTC (Table 2). Although no treatments separated from each other, they did reduce populations below threshold. All treatments three days after the second application (3DAT2) remained below threshold, but no differences were observed from the other treatments.

In 2013, results indicated all treatments reduced rice stink bugs below the UTC at five days after application (5 DAT; Table 3). Centric at 3.5 oz, Endigo ZC 5 oz, Endigo ZCX 6 oz, Tenchu 9 oz, CHA-3158 2.5 lb and 1.25 lb reduced rice stink bug numbers below threshold, while all other treatments did not. All treatments remained below the UTC 8 days after application (8 DAT) while Declare 1.54 oz did not reduce rice stink bug numbers below the economic threshold.

SIGNIFICANCE OF FINDINGS

The rice stink bug causes poor milling and yield loss for Arkansas producers. The use of insecticides gives producers the ability to significantly lower rice stink bug numbers. When populations are at moderate levels, many compounds are able to reduce rice stink bug below economic threshold with a single application; but when populations are high, multiple applications may be required to achieve control. Alternate insecticides such as Tenchu and Centric may help reduce the potential for resistance to pyrethroids. New products allow use of multiple modes of action, increased residual control, reduced number of applications, have excellent control compared to currently labeled products and may improve yield and quality of rice. The continued research of selected compounds is necessary for the control of the rice stink bug.

ACKNOWLEDGMENTS

We would like to acknowledge Perkins Farm and Moery Farm (Lonoke County), and Pearson Farm (Faulkner County) for their cooperation in this study. Funding for this project was provided by: Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board, Syngenta, Cheminova, and Mitsui.

LITERATURE CITED

Johnson, D.R., J. Bernhardt, J. Greene, G. Lorenz, and G. Studebaker. 2002. Fact Sheet FSA 7057. Rice Stink Bug in Arkansas. University of Arkansas Sytem Division of Agriculture Cooperative Extension Service publication. Available from: http://www.uaex.edu/Other_Areas/publications/PDF/FSA-7057.pdf

Table 1. Efficacy of selected insecticides for control of rice stink bugs in Arkansas, 2011.

Treatments	Rice Stink Bugs/10 sweeps 7/14/2011 6 DAT 1	7/26/2011 7 DAT 2
UTC[†]	83.3 a[‡]	30.5 a
Endigo ZC 5 oz	17.5 e	3.0 b
Endigo ZCX 5 oz	15.3 e	2.0 b
Karate Z 1.6 oz	60.3 abc	2.3 b
Karate Z 1.8 oz	48.0 bcd	2.8 b
Karate Z 2.56 oz	35.8 cde	1.5 b
Centric 3.5 oz	26.0 de	2.0 b
Tenchu 9 oz	22.8 de	1.5 b
Declare 1.54 oz	72.3 ab	1.5 b
Declare 2.05 oz	39.5 cde	1.5 b
MustangMaxx 2.65 oz	62.5 abc	0.5 b
MustangMaxx 4 oz	47.0 bcd	1.8 b

[†] UTC = untreated check.

[‡] Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

Table 2. Efficacy of selected insecticides for control of rice stink bugs in Arkansas, 2012.

Treatments	Rice Stink Bugs/10 Sweeps 8/21/2012 4 DAT 1	8/28/2012 7 DAT 1	9/7/2012 3 DAT 2
UTC[†]	13.3 a[‡]	11.0 a	8.3 a
Endigo ZC 5 oz	4.0 b	4.0 b	1.0 b
Endigo ZCX 5 oz	3.8 b	2.0 b	1.0 b
Karate Z 2.56 oz	4.8 b	3.8 b	0.0 b
Centric 3.5 oz	4.5 b	2.5 b	1.0 b
Tenchu 9 oz	5.3 b	3.5 b	1.3 b

[†] UTC = untreated check.

[‡] Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

Table 3. Efficacy of selected insecticides for control of rice stink bugs in Arkansas, 2013.

	Rice Stink Bugs/10 sweeps	
Treatments	5 DAT 8/5/2013	8 DAT 8/8/2013
UTC†	20.2 a‡	13.9 a
Declare 1.54 oz	10.7 b	7.7 b
Declare 2.05 oz	8.3 bc	4.1 c
Malathion 57 % 2 pints	7.9 bcd	3.7 c
Karate Z 2.56 oz	6.1 b-e	2.6 cd
CHA-3158 0.625 lb	5.5 cde	2.6 cd
CHA-3158 1.25 lb	4.9 c-f	2.2 cde
CHA-3158 2.5 lb	4.1 c-f	1.9 cde
Endigo ZCX 5 oz	3.8 def	1.9 cde
Tenchu 9 oz	3.4 ef	1.2 de
Endigo ZCX 6 oz	1.9 fg	0.9 de
Centric 3.5 oz	0.5 g	0.7 e

† UTC = untreated check.

‡ Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance Treatment P (F) is significant at mean comparison observed significance level.

Insecticide Seed Treatments in Rice: Is There Value to the Grower?

N.M. Taillon, G.M. Lorenz, J. Black, W.A. Plummer, and H.M. Chaney

ABSTRACT

Insecticide seed treatments have been evaluated for their impact on rice since 2007. A data analysis of plot trials conducted indicate that insecticide seed treatments can improve stand, increase vigor, protect the plant from major pests such as grape colaspis and rice water weevil but most importantly increase yield and profitability for the grower.

INTRODUCTION

Many of the insect pest problems associated with rice production cannot be solved with foliar insecticides. Particularly, the major insect pests of rice, the grape colaspis (GC), *Colaspis brunnea*, referred to by many growers as the "lespedeza worm," and, the rice water weevil (RWW), *Lissorhopterus oryzae*. Both of these pests have the potential to substantially reduce plant stand and subsequent yield in any given year. Prior to the development of new insecticide seed treatments in 2007, growers had few options for control of these key pests. Draining the field after infestation is still one of the most effective options, but the high cost of pumping in recent years has deterred growers from this practice (Thompson et al., 1994). Applying foliar insecticide has also been used as a means to control adult RWW and GC; however, difficulty in timing the application properly results in limited effectiveness.

Cruiser® 5FS (Syngenta Crop Protection) and Dermacor® X-100 (DuPont) were granted full labels for use during the spring of 2010. In the U.S. prior to 2010, an extensive testing program was conducted through Experimental Use Permits (EUPs). In 2008, Arkansas received a Section 18 with Louisiana and Mississippi for Dermacor and we were able to observe the product in large block trials to verify small block test results (Wilf et al., 2009a, 2009b, 2010a). In 2009 Dermacor received a full label and Arkansas was the only state granted a Section 18 for Cruiser. We were able to compare Cruiser to Dermacor and untreated checks in several locations across the rice growing area of the state in large and small plot trials (Wilf et al., 2010a, 2010b; Fortner et al., 2010, 2011a, 2011b, 2011c, 2011d, 2011e). In 2011, a third seed treatment, NipsIt Inside, became available on limited acreage; a EUP was granted on 40,000 acres of which 20,000 was allotted in Arkansas.

The opportunity to evaluate this product in small plots as well as on grower fields across the state provided a good opportunity to evaluate the product on large plot trials in the state (Lorenz et al., 2012; Plummer et al., 2012; Taillon et al., 2012; Thrash et al., 2012). NipsIt Inside (Valent) received a full label for use in the fall of 2012 (Everett et al., 2013; Plummer et al., 2012; Taillon et al., 2013a, 2013b). In 2011 the Cruiser formulation was changed to Cruiser Maxx Rice which includes a premix of Cruiser and fungicides.

PROCEDURES

Experiments and demonstrations were conducted from 2007 to 2013 on numerous grower fields across the state, the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and Rice Research Extension Center near Stuttgart, Ark. These trials consisted of small plot replicated experiments and large plot demonstration trials and the comments on these seed treatments herein, are based on these observations. In these trials we have used seeding rates ranging from 20 lb/acre to 120 lb/acre. We have observed these seed treatments on conventional, Clearfield and hybrid cultivars of rice. The selection of locations was based on fields with a history of problems with either grape colaspis or rice water weevil. However, we did not experience insect problems in every field.

A metadata analysis of impact on yield across these trials was conducted to determine the effect on yield for the insecticide seed treatments. Data is processed using the latest version of Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.), analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

Throughout the testing of these seed treatments we have seen a general trend to improve stand count and vigor in many fields with the use of seed treatments (Wilf et al., 2009b). Seed treatments have increased stand counts in many trials as much as 10% to 20% above the untreated check. We have also documented increased plant height in some fields (Wilf et al., 2009a, 2009b). The amount of vigor seen may be dependent on many factors including pest pressure, environmental conditions, and seed quality. Many times we have observed under stressful conditions the seed treatment helped to moderate or buffer stress including pressure caused by herbicide drift (Scott et al., 2013).

The insecticide seed treatments have continued to provide good control of RWW in Arkansas. Seed treatments provide good control when moderate populations of RWW are present on roots (Fortner et al., 2010, 2011a-e; Plummer et al., 2012; Taillon et al., 2012, 2013a, 2013b; Wilf et al., 2009a, 2009b, 2010a, 2010b). When higher populations occur (>20 larvae per core), NipsIt Inside and Cruiser provide adequate control while Dermacor provides a slightly higher level of control.

Each of the seed treatments provided substantial benefits in terms of yield (Figs. 1-3). Over the 8 year period, Dermacor provided an 8.67 bu/acre yield increase, Cruiser provided an 8.2 bu/acre yield increase, and NipsIt Inside provided an 8 bu/acre increase compared to the untreated check. Based on the yield results shown in the figures below, Dermacor, Cruiser, and NipsIt provided an 86%, 78%, and 72% probability of a net return, respectively.

SIGNIFICANCE OF FINDINGS

While our tests have demonstrated improved stand, increased vigor and control of some of the major pests associated with rice, including grape colaspis and rice water weevil, as well as buffering the impact of herbicide drift, the bottom line is profitability for rice producers. Insecticide seed treatments not only provide protection of the rice plant from insects and reduce stress, but increase yields and profitability.

ACKNOWLEDGMENTS

We would like to express our appreciation to Arkansas rice producers, Rice Research and Promotion Board, DuPont, Syngenta, and Valent for their support. We would also like to acknowledge the many county agents that helped with these trials.

LITERATURE CITED

Everett, M.E., G.M. Lorenz III, N.A. Slaton, J.T. Hardke, N.M. Taillon, B.C. Thrash, D.L. Clarkson, and L. Orellana-Jimenez. 2013. Efficacy of rice insecticide seed treatments at selected nitrogen rates for control of rice water weevil. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:109-115. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2010. Efficacy of selected insecticide seed treatments for the control of rice water weevils in large block studies in Arkansas rice, 2011. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:87-90. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2011a. Efficacy of cyazapyr for control of rice water weevil in Arkansas rice, 2010. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:91-93. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2011b. Efficacy of selected insecticide seed treatments for the control of rice water weevil across three seeding rates in Arkansas rice, 2010. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:97-100. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2011c. Efficacy of selected insecticide seed treatments for the control of rice water weevil across three seeding rates of CL151 in Arkansas rice, 2010. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:101-103. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2011d. Efficacy of selected insecticide seed treatments for the control of rice water weevil using hybrid varieties in Arkansas rice, 2010. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:104-106. Fayetteville, Ark.

Fortner, J., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2011e. Efficacy of selected compounds for control of rice water weevils in Arkansas rice, 2010. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:107-110. Fayetteville, Ark.

Lorenz III, G.M., A. Plummer, N. Taillon, B. Thrash, and J. Fortner. 2012. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:116-119. Fayetteville, Ark.

Plummer, A., G.M. Lorenz III, N. Taillon, B. Thrash, J. Fortner, and C.K. Colwell. 2012. Impact of insecticide seed treatments in large block field trials in Arkansas, 2009 to 2011. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:128-131. Fayetteville, Ark.

Scott, R.C., G.M. Lorenz III, J. Hardke, B. M. Davis, and J. Dickson, 2013. Use of CruiserMaxx rice seed treatment to improve tolerance of conventional rice to Newpath (imazethapyr) and Roundup (glyphosate) at reduced rates. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 617:227-233. Fayetteville, Ark.

Taillon, N., G.M. Lorenz III, A., Plummer, B. Thrash, J. Fortner, and C.K. Colwell. 2012. Efficacy of selected insecticide seed treatment at various seeding rates for conventional, Clearfield, and hybrid cultivars. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:132-137. Fayetteville, Ark.

Taillon, N., G.M. Lorenz III, A. Plummer, M.E. Everett, B. Thrash, D.L. Clarkson, and L. Orellana-Jimenez. 2013a. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:119-121. Fayetteville, Ark.

Taillon, N., G.M. Lorenz III, A. Plummer, M.E. Everett, B. Thrash, D.L. Clarkson, and L. Orellana-Jimenez. 2013b. Comparison of insecticide seed treatments for control of rice water weevil and grape colaspis. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:122-125. Fayetteville, Ark.

Thompson, R.A., S.S. Quisenberry, F.K. N'Guessan, A.M. Heagler, and G. Giesler. 1994. Planting date as a potential cultural method for managing the rice water weevil (Coleoptera: Curculioidae) in water seeded rice in southwest Louisiana. J. Econ. Entomol. 87:1318-1324.

Thrash, B.C., G.M. Lorenz, N.M. Taillon, W.A. Plummer, C.K. Colwell, and J.W. Fortner. 2012. Efficacy of selected insecticides for control of rice stink bug, *Oebalus pugnax*, in Arkansas. *In:* R.J. Norman and K.A.K. Moldenhaur (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:138-141. Fayetteville, Ark.

Wilf, H., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2009a. Efficacy of rice insecticide seed treatments for control of grape colaspis (*Colaspis brunnea*) and rice water weevil (*Lissorhoptrus oryzophilus* Kuschel). *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:135-139. Fayetteville, Ark.

Wilf, H., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2009b. Efficacy of rice insecticide seed treatments for control of rice water weevil (*Lissorhotrus oryzophilus* Kuschel) at two seeding rates. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:140-143. Fayetteville, Ark.

Wilf, H., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2010a. Comparing the efficacy of insecticide seed treatments at three seeding rates. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:104-108. Fayetteville, Ark.

Wilf, H., G.M. Lorenz III, K. Colwell, and N.M. Taillon. 2010b. Efficacy of selected insecticide seed treatments for control of grape colaspis and rice water weevil. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:109-113. Fayetteville, Ark.

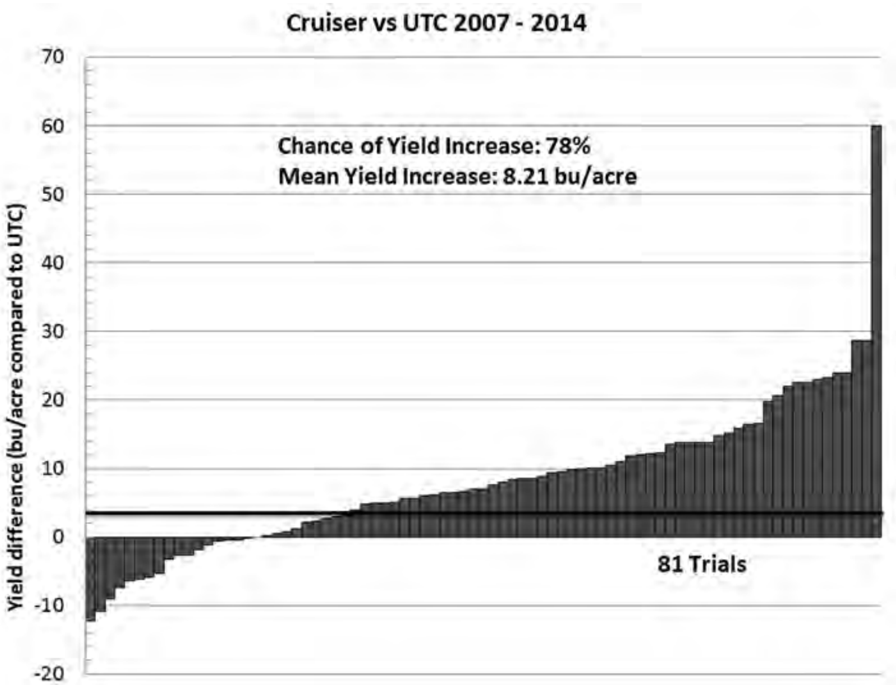


Fig. 1. Increase or decrease in yield for Cruiser insecticide seed treatment compared to an untreated check in 81 trials conducted from 2007-2014.

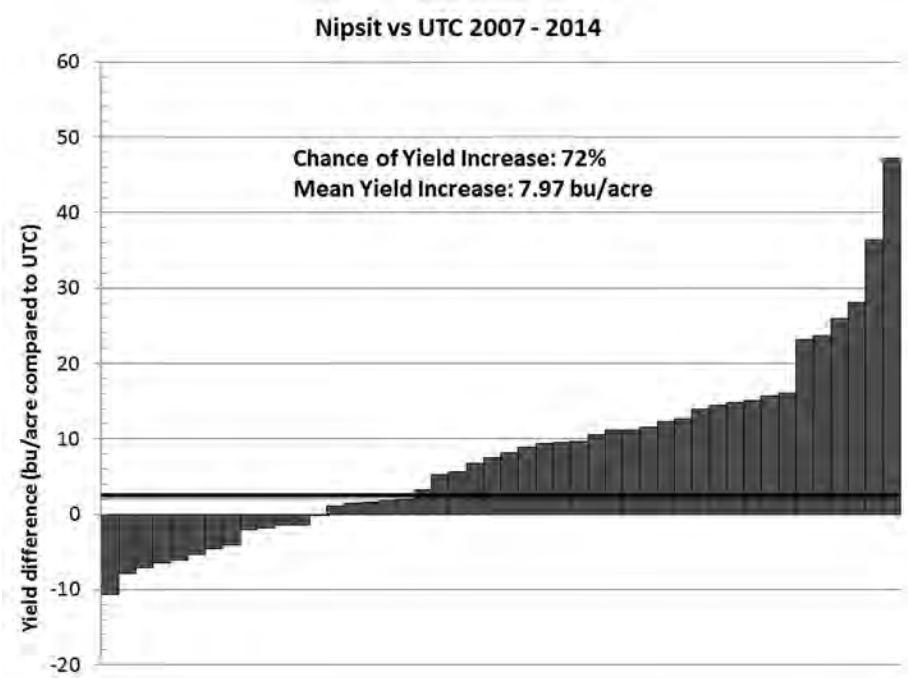


Fig. 2. Increase or decrease in yield for NipsIt insecticide seed treatment compared to an untreated check in 46 trials conducted from 2007-2014.

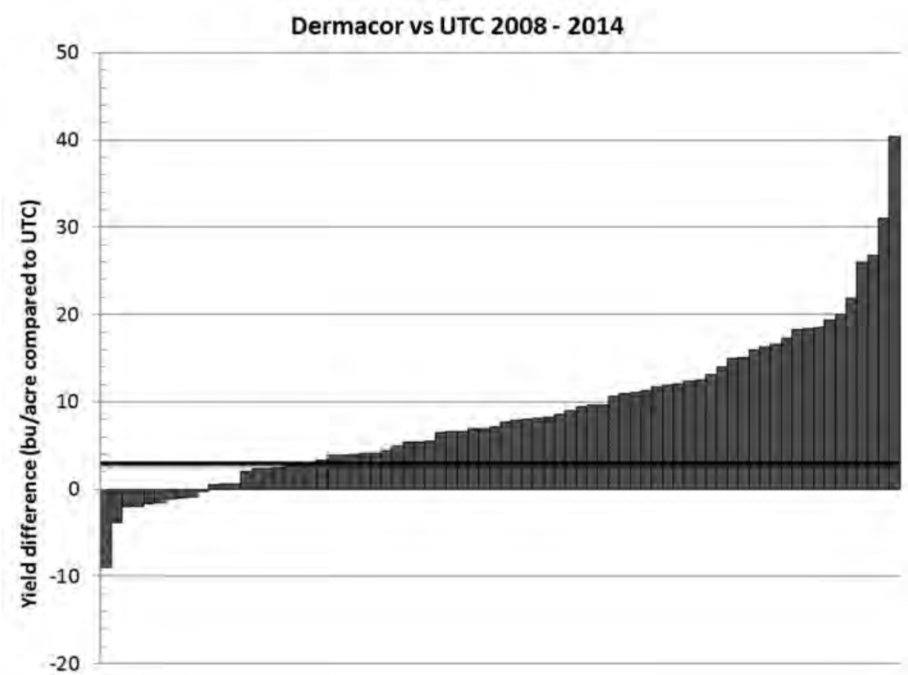


Fig. 3. Increase or decrease in yield for Dermacor X-100 (chlorantraniliprole) insecticide seed treatment compared to an untreated check in 74 trials conducted from 2007-2014.

Weed Control and Crop Response to Sharpen Tank Mixes in Rice

R.C. Doherty, L.T. Barber, L.M. Collie, and A.W. Ross

ABSTRACT

Alternate modes of action have become necessary for prevention and control of multiple weed species in Arkansas rice. In some areas of the state, the traditional programs still provide excellent weed control. In some rice production areas, traditional programs have been depended on solely and no longer provide adequate control of an ever-changing herbicide-resistant weed spectrum. Two trials were conducted in 2014 to evaluate weed control and crop response to Sharpen tank mixes in rice. Barnyardgrass and sprangletop control was improved when Rice Beaux or Riceshot plus Grandstand R were added to Sharpen at 1oz/acre plus crop oil concentrate (COC) at 1% v/v. Sharpen at 1 oz/acre plus COC at 1% v/v applied to 3-lf rice provided equal (99%) control of hemp sesbania (*Sesbania exaltata*) when compared to all the Sharpen systems that contained an emulsifiable concentrate (EC) herbicide or Propanil. No rice injury was caused by any treatment. Sharpen does provide an alternate mode of action in Arkansas rice weed control.

INTRODUCTION

Arkansas rice producers rely heavily on products such as Aim, Permit, Facet L, Regiment, Basagran, Londax, Propanil, and Grandstand R for broadleaf weed control. These herbicides are effective, but are becoming less effective in some areas due to over use. As weed management has become more challenging, rice producers are in need of a herbicide with a different mode of action to help prevent herbicide resistance. Sharpen (saflufenacil) received EPA registration for pre-emergence and post-emergence (POST) applications on rice in 2014. Use of Sharpen has proved to be beneficial when added to herbicide systems in other crops such as soybean, grain sorghum, and corn

(Scott et al., 2015). Camargo et al. (2012) reported that Sharpen applied POST in rice caused crop injury, but did not reduce yield. Montgomery et al. (2014) found that Sharpen provided excellent broadleaf weed control and caused minimal crop injury. The purpose of this research was to evaluate Sharpen post-emergence in rice for weed control and crop injury.

PROCEDURES

Two trials were conducted in 2014 at the University of Arkansas System Division of Agriculture's Southeast Research and Extension Center near Rohwer, Ark., to evaluate weed control and crop response to Sharpen tank mixes in rice. A randomized complete block design with four replications was used. The cultivar CL111was drill-seeded into Sharkey clay soil at 90 lb/acre, and weed seed was broadcast-seeded after planting. Treatments were applied using a Mudmaster equipped with a compressed air powered multi-boom calibrated to deliver 12 gal/acre. Treatments were applied to 3-lf rice in all treatments but one, where Sharpen was applied at 1 oz/acre post-flood. Weed control and crop injury were evaluated on a scale from 0 to 100% where 0 equals no weed control or crop injury and 100 equals complete control. Data were subjected to analysis of variance and means were separated using Fisher's Protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Barnyardgrass (*Echinochloa crus-galli*) and sprangletop (*Leptochloa fascicularis*) control 1 week post-flood (WPF) with all treatments, Sharpen alone or in combination with emulsifiable concentrate (EC) herbicides, was less than 67% (Table 1). Sharpen at 1 oz/acre plus crop oil concentrate (COC) at 1% v/v post-flood and Sharpen at 0.75 oz/acre plus COC at 1% v/v applied to 3-lf rice provided 90% and 89% control of hemp sesbania, respectively. All other treatments provided 99% control of hemp sesbania 1 WPF. No crop injury was observed by any treatment in the Sharpen EC combinations trial. Sharpen at 1 oz/acre plus Rice Beaux at 96 oz/acre plus COC at 1% v/v and Sharpen at 1 oz/acre plus Riceshot at 96 oz/acre plus Grandstand R at 16 oz/acre plus COC at 1% v/v applied to 3-lf rice provided 78% and 85% control 1 WPF of both barnyardgrass and sprangletop, respectively (Table 2). All other treatments provided 76% or less control of barnyardgrass and sprangletop. All treatments provided 99% control of hemp Sesbania 1 WPF. No crop injury was observed by any treatment, Sharpen alone or in combination with Propanil, 1 WPF.

SIGNIFICANCE OF FINDINGS

Barnyardgrass and sprangletop were controlled best (78% and 85%) by Sharpen plus Rice Beaux or Riceshot plus Grandstand R plus COC. All treatments provided excellent (99%) control of hemp sesbania 1 WPF. From these trials, the combination of sharpen with an EC herbicide or propanil did increase grass control, but did not increase hemp sesbania control 1WPF. No significant crop injury was caused by any treatment in either of these trials, which further supports the use of Sharpen in Arkansas rice weed control programs. However, physical burn can occur to rice following Sharpen applications and has been observed in other trials. Burn can be expected if rice is small (<3-lf) or under stress, or if rates of COC are increased to 1qt/acre.

ACKNOWLEDGMENTS

Special appreciation is extended to the Arkansas Rice Research and Promotion Board and the Arkansas rice growers for providing funding and support for these projects.

LITERATURE CITED

Camargo, E.R., S.A. Senseman, G.N. McCauley , and J.B. Guice. 2012. Rice (*Oryza sativa*) response and weed control from tank-mix applications of saflufenacil and imazethapyr. Crop Prot 30:94-98.

Montgomery, G.B., J.A. Bond, B.R. Golden, J. Gore, H.M. Edwards, T.W. Eubank, and T.W. Walker. 2014. Evaluation of saflufenacil in drill-seeded rice (*Oryza sativa*). Weed Technol. 28:660-670

Scott, R.C., L.T. Barber, J.W. Boyd, G. Selden, J.K. Norsworthy, and N.R. Burgos. 2015. MP44. Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service, Little Rock, Ark.

Table 1. Weed control and crop response to Sharpen tank mixed with emulsifiable concentrate herbicides one week post-flood.

			Weed control			Crop injury
Treatment	Rate/acre	Timing	Barnyardgrass	Sprangletop	Hemp sesbania	General phyto[a]
			(%)			
Sharpen	1 oz	3-lf rice	35	35	99	0
COC[b]	1%					
Sharpen	1 oz	3-lf rice	60	61	99	0
Stam M-4	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	65	66	99	0
Stam M-4	128 oz					
Sharpen	1 oz	3-lf rice	65	65	99	0
Rice Beaux	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	56	59	99	0
Rice Beaux	96 oz					
Sharpen	1 oz	3-lf rice	67	63	99	0
Facet L	32 oz					
Permit Plus	0.8 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	53	55	99	0
Super Wham	128 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	54	55	99	0
Facet L	32 oz					
Regiment	0.67 oz					
COC	1%					
Sharpen	1 oz	Post-flood	55	55	90	0
COC	1%					
Sharpen	0.75 oz	3-lf rice	37	38	89	0
COC	1%					
LSD (0.05)			2	18	9	NS

[a] Phyto = phytotoxicity.
[b] COC = crop oil concentrate.

Table 2. Weed control and crop response to Sharpen tank mixed with Propanil one week post-flood.

			Weed control			Crop injury
Treatment	Rate/acre	Timing	Barnyardgrass	Sprangletop	Hemp sesbania	General phyto[a]
			(%)			
Sharpen	1 oz	3-lf rice	30	30	99	0
COC[b]	1%					
Sharpen	1 oz	3-lf rice	76	76	99	0
Riceshot	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	55	55	99	0
SuperWham	128 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	70	70	99	0
RicePro	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	78	78	99	0
Rice Beaux	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	53	48	99	0
Duet	96 oz					
COC	1%					
Sharpen	1 oz	3-lf rice	71	71	99	0
Riceshot	96 oz					
Londax	0.533 oz					
COC	1 %					
Sharpen	1 oz	3-lf rice	85	85	99	0
Riceshot	96 oz					
Grandstand R	16 oz					
COC	1%					
LSD (0.05)	26	25	NS	NS		

[a] Phyto = phytotoxicity.
[b] COC = crop oil concentrate.

Residual Activity of Quizalofop on Grass Weeds and Crops Compared to Other Graminicides

Z.D. Lancaster, J.K. Norsworthy, M.G. Palhano, S.M. Martin, R.R. Hale, and R.C. Scott

ABSTRACT

With the evolution of weeds that have resistance to multiple herbicide modes of action, a new technology is needed to control many of these troublesome weeds. BASF is currently developing new rice cultivars that will be resistant to quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide (Group 1). A field experiment was conducted in the summer of 2014 at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center in Fayetteville, Ark., to evaluate the residual activity of quizalofop relative to other graminicides for crop injury and grass weed control. The experiment was set up as a split-split plot design assigning herbicide activation as the whole plot factor, with plant-back date as the subplot, and herbicide treatments as the sub-subplot. This experiment was evaluated for four different crops (conventional rice, Provisia rice, grain sorghum, and corn). Herbicide treatments were 1× and 2× label rates of quizalofop (Targa), fenoxaprop (Ricestar HT), cyhalofop (Clincher), fluazifop (Fusilade DX), clethodim (SelectMax), and sethoxydim (Poast). Overhead irrigation in the amount of 0.5 inch was applied immediately after applying the herbicides, and the plant-backs were made at 0, 7, and 14 days after treatment (DAT). For all crops, injury from herbicide treatments generally increased with activation over no activation. Provisia rice exhibited a high level of tolerance to each of the evaluated herbicides, whereas injury to conventional rice was no more than 13%. More injury was observed on corn and grain sorghum than on rice. All herbicides controlled emerged broadleaf signalgrass more than 80%, but provided little residual control. The results of this experiment suggest that caution will need to be taken for immediate plant-back behind these herbicides and crop selection will be important for minimizing injury risks.

INTRODUCTION

A major obstacle to Arkansas rice production is weed control. Weeds compete with rice for sunlight, water, nutrients, and other growth requirements (Smith, 1988). In a 2011 survey, 63% of Arkansas crop consultants listed barnyardgrass as the most problematic weed of rice, with red rice ranking second (Norsworthy et al., 2013). Red rice and barnyardgrass can potentially cause yield losses as high as 82% and 70%, respectively (Smith, 1988).

Barnyardgrass has evolved resistance to multiple herbicides used in Arkansas rice, the first of which was propanil in the early 1990s (Carey et al., 1995). Poor stewardship of alternative herbicides led to continued herbicide-resistance of barnyardgrass to quinclorac, clomazone, and the imidazolinone herbicides used in Clearfield™ rice (Talbert and Burgos, 2007; Norsworthy et al., 2013). With the evolution of weeds that have resistance to multiple herbicide modes of action, a new technology is needed to control many of these troublesome weeds. BASF is currently developing a new herbicide-resistant rice technology that will allow for topical applications of quizalofop, an acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicide. Quizalofop will be primarily used in the Provisia rice system to control barnyardgrass and red rice. With the anticipated launch of Provisia rice within the next 3 to 4 years, research is needed to understand the best fit for this technology in Arkansas rice production systems.

PROCEDURES

An experiment was set up to determine the length of residual activity that could be expected on grass crops and grass weeds following quizalofop application relative to other similar herbicides. The field experiment was conducted in the summer of 2014 at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center in Fayetteville, Ark., on a leaf silt-loam soil. The experiment was set up as a split-split plot design, with the whole plot factor being herbicide activation, subplot factor being plant-back timing, and the sub-subplot factor being herbicide treatment. Plots had either a 0.5-inch overhead irrigation applied with a traveling gun sprinkler system to insure herbicide activation or no irrigation. Crops evaluated were conventional rice, Provisia rice, grain sorghum, and corn. Plant back timings for crops were 0, 7, and 14 days after herbicide treatment. Herbicides were applied to a tilled bare soil before any crops were planted using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Herbicides treatments evaluated are listed in Table 1 with some being applied at high (H) and low (L) rates. Plot size was 6 ft × 25 ft. The plots were over-sprayed with 1 pt/acre of Weedar (2,4-D) at 2 wk and 4 wk after initiating experiment to insure control of broadleaf weeds. Visual observations were taken for crop injury and weed control on a scale of 0 to 100 with 0 being no injury or weed control and 100 being complete crop death or weed control. All data were processed using analysis of variance with SAS 9.4 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

All crops in this experiment were injured by the residual activity of the evaluated herbicides, except for Provisia rice which showed tolerance to several of the herbicides (data not shown). Provisia rice injury resulted in no significant interactions or main effects, with no more than 4% injury observed. Conventional rice showed higher levels of injury across herbicide treatments. For conventional rice, there was a significant activation by herbicide treatment interaction. The presence or absence of activation had no significant effect on injury of the herbicides applied at the low rates (Fig. 1). Fusilade and Poast at the high rate and Targa at both rates caused the highest injury to conventional rice. Injury to conventional rice from Poast applied at the high rate with activation was greater than with no activation and greater than when applied at the low rate with or without activation. No injury to conventional rice was observed for Targa, Ricestar, Clincher, and Poast without activation.

For grain sorghum, there was a significant activation by herbicide interaction. The greatest injury was produced with Poast at the high rate with activation at 20% (Fig. 2). Targa at the low and high rate were not different from each other, resulting in 13% to 14% injury. Six of the ten herbicide treatments caused greater injury to grain sorghum when activated following application. Grain sorghum also resulted in a significant activation by plant-back timing interaction. Greater injury was observed at 7 DAT and 14 DAT, but not at 0 DAT (Fig. 3). Injury increased as plant-back timing increased with the greatest injury being at 14 DAT when activated. The increased injury at 14 DAT may be due to herbicide going into soil solution and leaching to greater depths in the soil profile with rain events.

Corn showed a similar pattern of injury as grain sorghum. There was a significant activation by herbicide interaction. The greatest injury was caused by Poast at a high rate with activation (Fig. 4). Only four of ten herbicide treatments resulted in greater injury to corn with activation than with no activation.

Grass control, mainly broadleaf signalgrass, was also rated in this trial. Across all herbicide treatments, broadleaf signalgrass control ranged from 82% to 91%, with few differences observed among treatments (Fig. 5). Most of the broadleaf signalgrass control observed following these treatments was likely a result of controlling small plants that were present at the time of application and it is unlikely that much residual control was provided by any of these treatments. This conclusion is partially based on the fact that subsequent emergence of broadleaf signalgrass was readily observed in these plots following the 14 DAT evaluation.

SIGNIFICANCE OF FINDINGS

The significance of this research is primarily for plant-back timings for crops. The results from this experiment demonstrate that there is little or no risk for injury to Provisia rice from preplant applications of ACCase-inhibiting herbicides, and injury to conventional rice can be slight if planted in close proximity to an ACCase herbicide application. Injury from the evaluated herbicides appears more likely for grain sorghum and corn than rice. For almost all treatments, activation of the herbicide increased injury to crops, and few differences were observed among herbicides for broadleaf signalgrass control.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

LITERATURE CITED

Carey, V.F., R.E. Hoagland, and R.E. Talbert. 1995. Verification and distribution of propanil-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas. Weed Technol. 9:366-372.

Norsworthy, J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623-630.

Smith, R.J. 1988. Weed thresholds in southern U.S. rice, *Oryza sativa*. Weed Technol. 2:232-241.

Talbert, R.E. and N.R. Burgos. 2007. History and management of herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas rice. Weed Technol. 21:324-331.

Table 1. Herbicide treatments applied before first planting at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center in Fayetteville, Ark.

Treatments[a]	Rate	Trade name
Quizalofop (L)	10.34 fl oz/acre	Targa
Quizalofop (H)	20.68 fl oz/acre	Targa
Clethodim (L)	8 fl oz/acre	SelectMax
Clethodim (H)	16 fl oz/acre	SelectMax
Fenoxaprop	24 fl oz/acre	Ricestar HT
Cyhalofop	15 fl oz/acre	Clincher
Fluazifop (L)	12 fl oz/acre	Fusilade DX
Fluazifop (H)	24 fl oz/acre	Fusilade DX
Sethoxydim (L)	1 pt/acre	Poast
Sethoxydim (H)	2 pt/acre	Poast

[a] L = low rate and H = high rate of application.

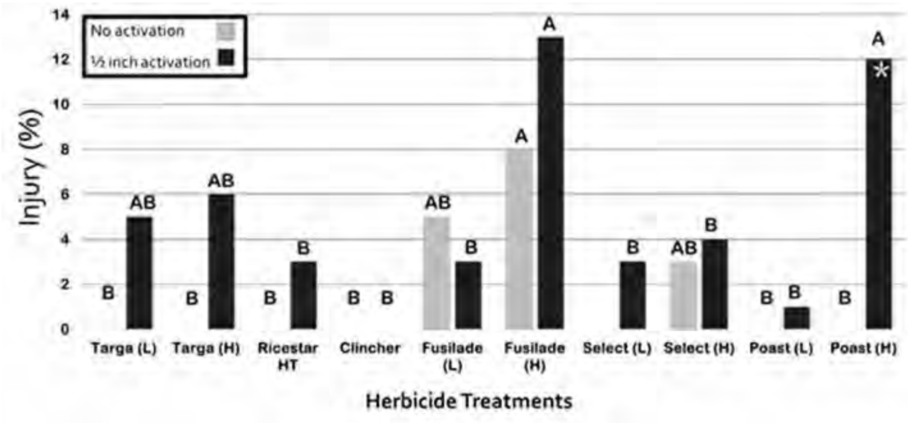


Fig. 1. Interaction of herbicide activation and herbicide selection on conventional rice injury at 2 weeks after emergence. Uppercase letters are used to separate means within 0.5 inch activation treatments and lowercase letters are used for mean separation within no activation. Asterisks represent treatments that were significantly different between activation treatments within a herbicide treatment. Some herbicides were applied at a low (L) and high (H) rate.

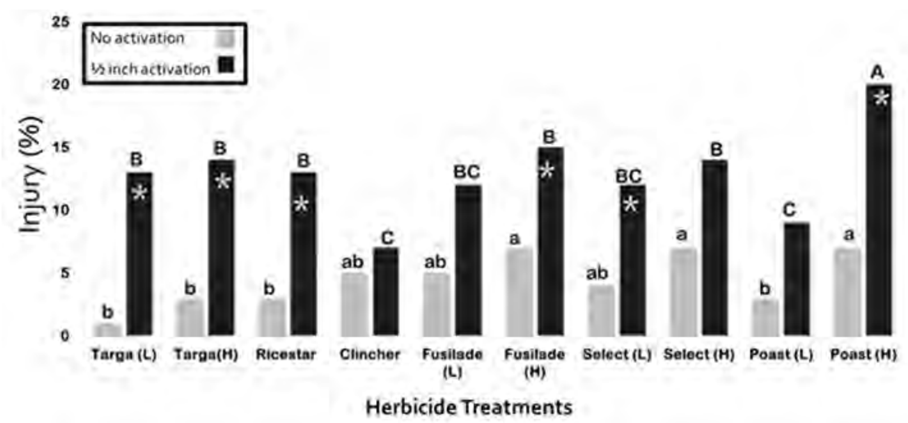


Fig. 2. Interaction of herbicide activation and herbicide selection on grain sorghum injury at 2 weeks after emergence. Uppercase letters are used to separate means within 0.5 inch activation treatments and lowercase letters are used for mean separation within no activation. Asterisks represent treatments that were significantly different between activation treatments within a herbicide treatment. Some herbicides were applied at a low (L) and high (H) rate.

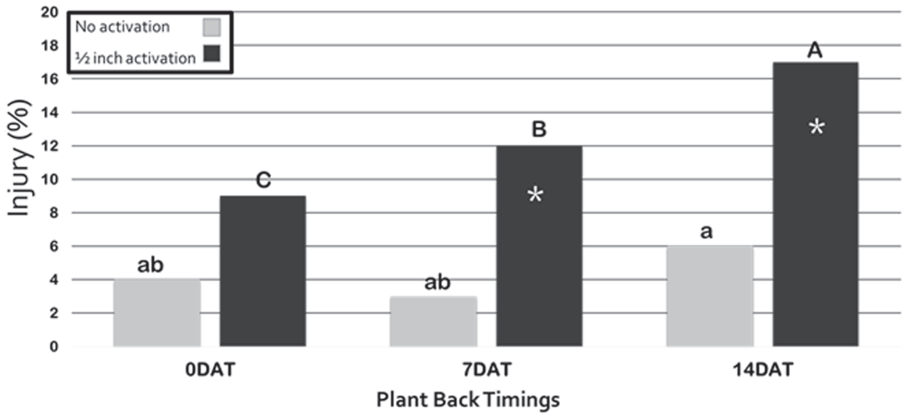


Fig. 3. Grain sorghum injury at 2 weeks after emergence. Significant activation by plant-back timing interaction was observed. Uppercase letters are used to separate means within 0.5 inch activation treatments and lowercase letters are used for mean separation within no activation. Asterisks represent treatments that were significantly different between activation treatments within a plant-back timing.

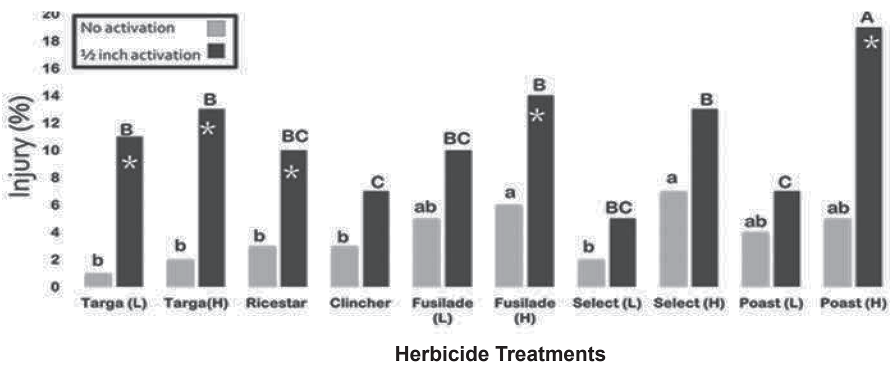


Fig. 4. Interaction of herbicide activation and herbicide selection on corn injury at 2 weeks after emergence. Uppercase letters are used to separate means within 0.5 inch activation treatments and lowercase letters are used for mean separation within no activation. Asterisks represent treatments that were significantly different between activation treatments within a herbicide treatment. Some herbicides were applied at a low (L) and high (H) rate.

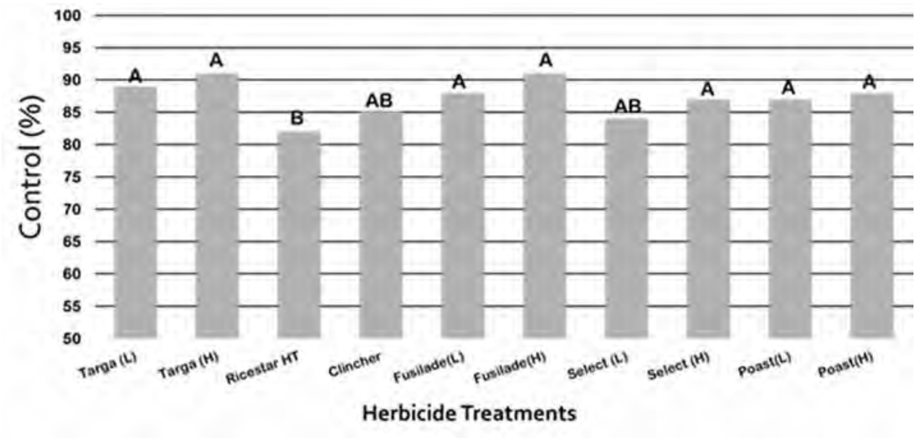


Fig. 5. Broadleaf signalgrass control at 2 weeks after herbicide application.

Comparison of Insecticide Seed Treatments for Lessening Rice Injury Following Herbicide Drift

S.M. Martin, J.K. Norsworthy, R.C. Scott,
G.M. Lorenz III, J. Hardke, and Z.D. Lancaster

ABSTRACT

Every year there are multiple reports of drift occurrence in rice. With a large percentage of other crops being Roundup Ready (glyphosate-resistant) and approximately 50% of Arkansas rice being non-Clearfield (imidazolinone-resistant), the majority of drift complaints in rice are from Newpath (imazethapyr) and Roundup (glyphosate). In 2014, a field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Ark.,and at the University of Arkansas Pine Bluff (UAPB) Farm near Lonoke, Ark., to evaluate whether or not insecticide seed treatments could reduce injury from Roundup or Newpath drift or decrease the recovery time of the rice. Roy J rice was planted and simulated drift events of a 1/10× rate of Newpath or Roundup was applied to each plot. Each plot had either a seed treatment of CruiserMaxx Rice, NipsIt Inside, Dermacor X-100, or no seed treatment. The simulated drift event was applied at the 2- to 3-lf growth stage. Crop injury was assessed at 11, 21, 26, and 40 days after treatment (DAT) at both locations. At 11 DAT, the Dermacor and NipsIt Inside seed-treated rice showed reduced injury from low rates of Roundup, and rice treated with NipsIt Inside or CruiserMaxx Rice showed reduced injury from Newpath. At RREC, CruiserMaxx Rice and NipsIt reduced injury from Newpath initially while NipsIt Inside also provided reduced injury from Roundup drift. CruiserMaxx Rice protected the yield potential of the rice after Roundup and Newpath drift at both locations, whereas NipsIt Inside protected rice against yield loss from Roundup drift. Based on these results, CruiserMaxx Rice and NipsIt Inside have the greatest potential to provide some protection against Newpath and Roundup drift.

INTRODUCTION

Each year in Arkansas roughly half of the rice acres are planted in Clearfield rice varieties and the other half remains in conventional rice varieties that are susceptible to injury from Newpath (imazethapyr) and Beyond (imazamox) herbicides that are applied to Clearfield rice (Hardke and Wilson, 2013). Injury to conventional rice from these acetolactate synthase (ALS)-inhibiting herbicides can come from physical drift or tank contamination while complete crop loss can come from an accidental application. Also, the most abundant crop planted in Arkansas and most widely used rotational crops to rice is soybean. Last year over 3.3 million acres of soybean were planted in the state with a majority of those being Roundup Ready soybean. Most soybeans are grown in close proximity to rice and present a threat of Roundup (glyphosate) drifting onto these rice fields. In previous research, drift rates of Newpath and Roundup caused significant yield reductions in rice (Kurtz and Street, 2003; Hensley et al., 2012).

Insecticide seed treatments provide critical protection to rice crops from rice water weevils and Grape colaspis (Lorenz et al., 2013). Currently in Arkansas roughly 60% of all rice acres receive some form of an insecticide seed treatment (Hardke, 2014). Some of the most widely used insecticide seed treatments are CruiserMaxx Rice, NipsIt Inside, and Dermacor X-100. All three of these insecticide seed treatments have been proven to be effective against rice water weevil (Lorenz et al., 2012). In addition to controlling rice water weevil, later studies have shown that these insecticide seed treatments have also provided increased yields (Plummer et al., 2012; Taillon et al., 2012). In 2010 and 2011, Gus Lorenz, State Extension Entomologist, University of Arkansas System Division of Agriculture, noticed that some of his trials that had received an insecticide seed treatment recovered quicker after an herbicide drift event occurred from a neighboring field. This observation was later confirmed by a study conducted by Bob Scott, State Extension Weed Scientist, University of Arkansas System Division of Agriculture, in 2013 at the University of Arkansas at Pine Bluff (UAPB) Farm near Lonoke Ark. A safening effect from CruiserMaxx Rice to reduce injury and increase yields after either a Newpath or Roundup drift event onto rice was observed (Scott et al., 2014).

The objective of this experiment was to compare the safening effect of CruiserMaxx Rice to NipsIt Inside and Dermacor X-100 following a simulated drift rate of Newpath and Roundup on conventional rice.

PROCEDURES

This experiment was conducted at the UAPB Farm near Lonoke, Ark., and the RREC, near Stuttgart, Ark., during the summer of 2014. Both locations were planted with conventional rice (i.e., Roy J) with the RREC location being planted on 23 April and the UAPB location being planted on 20 May. Both locations were planted with a cone-drill calibrated to a seeding rate of 75 lb/acre on rows spaced 7.5 inch.

The study was organized using a randomized complete block design with four replications and two factors. Factor A, insecticide seed treatment, consisted of CruiserMaxx Rice (7 oz/cwt), NipsIt Inside (1.92 oz/cwt), Dermacor X-100 (2.5 oz/cwt), and a nontreated (fungicide only) check. Factor B, simulated herbicide drift, consisted of Newpath (0.6 fl oz/acre), Roundup PowerMax (2.2 fl oz/acre), and a nontreated check.

The herbicide treatments were applied at the 2- to 3-lf growth stage of the rice at 15 gal/acre. The plots were kept weed free with Command and Facet at planting and followed University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations as needed throughout the season. The rice was fertilized according to the CES recommendations for soil fertility.

Data collection included stand counts, injury estimates, canopy height, rice water weevil counts, percent rice heading, and rough-rice grain yield. Data were analyzed using JMP Pro 11 (SAS Institute Inc., Cary, N.C.) and Fisher's protected least significant difference test was used to separate means at the 0.05 level.

RESULTS AND DISCUSSION

Rice Research and Extension Center

There was a significant interaction between the seed treatment and herbicide factors. The first injury ratings were taken 11 days after treatment (DAT) and injury symptoms were evident for both the Roundup and Newpath treatments, ranging from 8% to 19% injury (Table 1). By 21 DAT, injury had substantially increased from the previous rating for both Newpath and Roundup simulated drift. Rice injury from Roundup and Newpath drift at 21 DAT averaged 39% and 50%, respectively, in plots not treated with an insecticide seed treatment. Rice injury following Roundup drift at 21 DAT was only 19% in plots having a NipsIt Inside seed treatment, whereas both NipsIt Inside and CruiserMax significantly reduced rice injury caused by Newpath drift.

Rice grown from nontreated seed had 50% injury by 26 DAT, with Dermacor and CruiserMaxx Rice treated plots having significantly less injury (Table 1). Injury to Newpath treated rice continued to increase, with an estimated 70% injury observed on plants grown from nontreated seed. Protection from Newpath drift at 26 DAT was evident for seed treated with NipsIt Inside or CruiserMaxx Rice. By 40 DAT, all insecticide seed treatments provided some safening to Roundup drift; albeit, CruiserMaxx Rice was superior to Dermacor but not NipsIt Inside. In regard to rice injury from Newpath at 40 DAT, only CruiserMaxx Rice and NipsIt Inside provided some safening.

All treatments that received an insecticide seed treatment and Newpath drift had significantly greater canopy heights at 82 DAT compared to rice grown from the non-treated seed that received Newpath drift (Table 1). The treatments that received either a NipsIt Inside or CruiserMaxx Rice seed treatment, with Roundup drift, had a significantly taller canopy (>10 cm) than the rice grown from the nontreated seed that received Roundup drift. All treatments that received an insecticide seed treatment and Newpath or Roundup drift had similar canopy heights as the nontreated seed with no herbicide drift.

Percent heading was taken 97 DAT to determine if the drift events delayed heading in the rice. All treatments that received an insecticide seed treatment and no herbicide drift event were 74% to 85% headed at the time of evaluation (Table 1). The rice grown from the nontreated seed that had Roundup drift was only 15% headed, which was comparable to Dermacor treatment that received Roundup drift. The rice grown from the nontreated seed that had Newpath drift was 24% headed at the time of evaluation, which was not different from the corresponding Dermacor and NipsIt Inside treatments. Results from this experiment indicate CruiserMaxx Rice minimizes the risk for delayed heading following Newpath drift, and CruiserMaxx Rice and NipsIt Inside protects rice against delayed heading following Roundup drift.

Rice yield and grain moisture were taken 147 DAT and converted to a standard yield with a standard moisture of 12% (Table 1). The overall yield was influenced by the injury sustained throughout the season, as indicated by the injury ratings. Yield of plants with Newpath drift was affected more than plants with Roundup drift, with the exception being the CruiserMaxx Rice treated seed, where yields were not different between the two herbicides. Rice grown from the nontreated seed that received Roundup drift yielded 92 bu/acre, while rice grown from both the CruiserMaxx Rice and NipsIt Inside treated seed yielded significantly higher with 136 and 129 bu/acre, respectively. The lowest yielding treatments with Newpath drift were the Dermacor and nontreated seed with yields of 71 and 54 bu/acre, respectively. Overall, CruiserMaxx Rice protected the yield of the rice from Newpath drift, and all three seed treatments protected the yield similarly from Roundup drift.

University of Arkansas at Pine Bluff

Significant injury to the rice plants was visible from Newpath and Roundup drift by 11 DAT (Table 2). Overall, the Roundup drift caused more rice injury than the Newpath drift at this point. The rice grown from the nontreated and the Dermacor seed treatment were injured significantly more than the other treatments with Roundup drift. For the treatments that received Newpath drift, the CruiserMaxx Rice treated seed had the least injury (19%) while none of the other treatments were different from each other with injury ranging from 30% to 35%.

By 26 DAT, the least amount of rice injury from Roundup drift was when the rice seed was treated with either CruiserMaxx Rice or NipsIt Inside (Table 2). Injury from Newpath drift at 26 DAT was less when the seed was treated with CruiserMaxx Rice compared to Dermacor and no seed treatment and not significantly different when compared to NipsIt Inside. Dermacor and NipsIt Inside provided no significant protection of the rice plants from Newpath injury by 26 DAT than when the seed was not treated.

Canopy heights were not a good indicator of differences in the safening potential among the insecticide seed treatments (Table 2). Heading was delayed for rice not having an insecticide seed treatment or when treated with Dermacor relative to rice seed treated with CruiserMaxx Rice or NipsIt Inside. CruiserMaxx Rice and NipsIt Inside seed treatments protected rice against significant yield loss following Roundup drift. No significant yield loss was observed following Newpath drift, regardless of whether the seed was treated with an insecticide or not.

SIGNIFICANCE OF FINDINGS

The added benefits of insecticide seed treatments to young rice plants in protecting against rice water weevil and Grape colaspis is undeniable. However, the ability of some of these insecticide seed treatments to reduce injury from herbicide drift could add more return for the money spent on these seed treatments. The ability of the CruiserMaxx Rice seed treatment to achieve at least 90% relative yield in rice in the presence of both Roundup and Newpath drift could help farmers overcome drift events without relying on insurance or litigation. In return, insurance companies and the state could save money on the reduction in the number of drift complaints reported each year to the Arkansas State Plant Board. In addition, this could also allow conventional rice to be planted in closer proximity to Clearfield rice and Roundup Ready soybean.

ACKNOWLEDGMENTS

Special thanks to the Rice Research and Promotion Board and Syngenta Crop Protection for providing funding and support for this project.

LITERATURE CITED

Hardke, J.T. 2014. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Arkansas Wells Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:13-23. Fayetteville, Ark.

Hardke, J.T. and C.E. Wilson. 2013. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:38-47. Fayetteville, Ark.

Hensley, J.B., E.P. Webster, D.C. Blouin, D.L. Harrell, and J.A. Bond. 2012. Impact of drift rates of imazethapyr and low carrier volume on non-Clearfield Rice. Weed Technol. Vol. 26:236-242.

Kurtz, M.E. and J.E. Street. 2003. Response of rice (*Oryza sativa*) to glyphosate applied to simulate drift. Weed Technol. 17:234-238.

Lorenz, G.M., A. Plummer, N.M. Taillon, B. Thrash, J. Fortner, and K. Colwell. 2012. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:116-119. Fayetteville, Ark.

Lorenz G.M., N.M. Taillon, J.T. Hardke, and G. Studebaker. 2013. FSA7085. Rice insecticide seed treatments: Is there value to the Arkansas rice producer? University of Arkansas System Division of Agriculture's Cooperative Extension Service Publication Fact Sheet, Little Rock, Ark.

Plummer, W.A., G.M. Lorenz, N.M. Taillon, B.C. Thrash, J.W. Fortner, and C.K. Colwell. 2012. Impact of insecticide seed treatments in large block field trials in Arkansas 2009-2011. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:181-131. Fayetteville, Ark.

Scott, R.C., G.M. Lorenz III, J.T. Hardke, B.M. Davis, and J.W. Dickson. 2014. Use of CruiserMaxx® Rice seed treatment to improve tolerance of conventional rice to Newpath (imazethapyr) and Roundup (glyphosate) at reduced Rates. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:227-233. Fayetteville, Ark.

Taillon N.M., G.M. Lorenz III, W.A. Plummer, B.C. Thrash, J.W. Fortner, and C.K. Colwell. 2012. Efficacy of selected insecticide seed treatments at various seeding rates for conventional, Clearfield, and hybrid cultivars. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:132-137. Fayetteville, Ark.

Table 1. Effect of Newpath and Roundup drift rates on Roy J rice with either CruiserMaxx Rice, NipsIt Inside, Dermacor X-100, or no insecticide seed treatment grown at the Rice Research and Extension Center near Stuttgart, Ark., in 2014.

Treatment	Injury 11DAT[a]	Injury 21DAT	Injury 26DAT	Injury 40DAT	Canopy 82DAT	Groundcover 40DAT	Heading 97DAT	Yield 147DAT	Relative yield
	(%)				(cm)	(%)		(bu/acre)	(%)
CruiserMaxx No herbicide	0	0	0	0	86	48	81	137	100
NipsIt No herbicide	0	0	0	0	88	51	85	144	105
Dermacor No herbicide	0	0	0	0	86	35	74	135	99
No seed trt[b] No herbicide	0	0	0	0	83	40	61	137	100
CruiserMaxx Roundup	13	29	34	38	87	24	54	136	99
NipsIt Roundup	11	19	44	46	87	35	65	129	94
Dermacor Roundup	8	30	33	55	82	16	33	120	88
No seed trt Roundup	19	39	50	71	74	8	15	92	67
CruiserMaxx Newpath	8	34	43	51	83	27	56	125	91
NipsIt Newpath	17	30	55	70	80	25	39	86	63
Dermacor Newpath	14	65	66	94	78	3	21	71	52
No seed trt Newpath	16	50	70	90	67	3	24	54	39
LSD (0.05)	8	13	15	15	8	25	22	28	_

[a] DAT = days after treatment.

Table 2. Effect of Newpath and Roundup drift rates on Roy J rice with either CruiserMaxx Rice, NipsIt Inside, Dermacor X-100, or no insecticide seed treatment grown at the University of Arkansas at Pine Bluff Farm near Lonoke, Ark., in 2014.

	Injury				Canopy	Groundcover	Heading	Yield	Relative
Treatment	11DAT[a]	21DAT	26DAT	40DAT	82DAT	40DAT	97DAT	147DAT	yield
	(%)				(cm)	(%)		(bu/acre)	(%)
CruiserMaxx No herbicide	0	0	0	0	83	58	88	202	104
NipsIt No herbicide	0	0	0	0	78	47	83	201	104
Dermacor No herbicide	0	0	0	0	75	37	79	194	100
No seed trtb No hrbicide	0	0	0	0	78	36	76	194	100
CruiserMaxx Roundup	26	20	10	7	78	37	79	197	102
NipsIt Roundup	36	32	13	7	77	35	78	195	101
Dermacor Roundup	46	41	25	18	71	19	51	170	88
No seed trt Roundup	49	51	29	19	71	19	43	165	85
CruiserMaxx Newpath	19	15	4	3	76	36	85	187	96
NipsIt Newpath	30	24	9	5	76	37	86	199	103
Dermacor Newpath	35	31	14	8	73	26	59	185	95
No seed trt Newpath	35	33	13	5	80	37	73	197	102
LSD (0.05)	7	8	9	10	7	15	17	18	--

[a] DAT = days after treatment.

Use of Cruiser Maxx® Rice Seed Treatment to Improve Tolerance of Conventional Rice to Newpath (Imazethapyr) and Roundup (Glyphosate) at Reduced Rates Over 2 Years

R.C. Scott, G. Lorenz, J.T. Hardke, J.K. Norsworthy, and B.M. Davis

ABSTRACT

A field trial was conducted in 2013 and again in 2014 to evaluate the effect of the insecticide seed treatment Cruiser Maxx Rice on exposure of young conventional rice (Roy J) to the herbicides glyphosate (Roundup) and imazethapyr (Newpath). Rice seed was treated with 7 oz/100 lb of Cruiser Maxx Rice which contains thiamethoxam insecticide, a neonicotinoid class of insecticide, plus a fungicide mixture (treated seed) and compared to seed that was treated with the same components minus the thiamethoxam (untreated). Rice plants from seed treated with Cruiser Maxx Rice were able to tolerate significant amounts of both imazethapyr and glyphosate in comparison to rice of untreated seed receiving the same herbicide treatments. Newpath rates evaluated were 1.0, 0.5 and 0.25 oz/acre; Roundup PowerMax (hereafter Roundup) rates evaluated were 4.0, 2.0, and 1.0 fl oz/acre. Treatments were applied to 3-lf rice. When averaged over 2 years, Newpath applied at 0.5 fl oz/acre caused over 30% more visible injury at 42 days after treatment and resulted in a 100 bu/acre yield decrease in 2013 and a 30 bu/acre reduction in 2014 for rice from nontreated seed compared to rice from seed treated with Cruiser Maxx Rice. Similarly rice from seed treated with Cruiser Maxx Rice and then exposed to 4 fl oz/acre of Roundup yielded 70 (2013) and 20 (2014) bu/acre more than the rice from nontreated seed. Positive effects of the seed treatments were seen in days to heading, canopy height, yield, and visible injury at all rates evaluated in 2013 and to a lesser extent in 2014.

INTRODUCTION

Currently, approximately 50% of the rice grown in Arkansas is Clearfield rice and receives applications of the herbicides Newpath (imazethapyr) or Beyond (imazamox)

(Hardke and Wilson, 2012; Wilson et al., 2010). The other 50% of rice grown in the state lacks the Clearfield tolerance trait and is therefore susceptible to injury if Newpath or Beyond is somehow applied to the field either through tank-contamination, drift, or by accidental application. In addition, there are over 3 million acres of soybean grown in Arkansas in close proximity to rice. The majority of these soybean acres are Roundup Ready and receive applications of the herbicide Roundup (glyphosate). Previous research has shown that both Newpath and Roundup can be harmful to rice yields depending on rate and timing of exposure (Davis et al., 2011; Hensley et al., 2012).

In previous research, York et al. (1991) found that disulfoton and phorate greatly reduced clomazone injury to cotton when applied in-furrow. Similar results with the in-furrow applications of phorate were also documented; however not of the insecticide aldicarb in 1990 and 1991 (York and Jordan, 1992). Both these reductions in crop injury were observed in the relative absence of insect pressure. This effect was later quantified in the lab by Culpepper et al. (2001). They determined that this "safening effect" was due to the insecticide causing a change in the metabolism of clomazone in cotton, suggesting that some clomazone metabolite may be more toxic to cotton than the compound itself. Nonetheless, this work does represent a precedent for using a soil or in-furrow insecticide treatment to "safen" a crop to a given herbicide. In fact, this was a common practice throughout the mid to late 1990s and early 2000s in cotton production prior to the introduction of Roundup Ready™ Cotton (Culpepper et al., 2001).

Wilf et al. (2010) and later Plummer et al. (2012) have documented many benefits of soil insecticide treatments in rice. Some of these benefits include overall improved plant vigor that may or may not be due to insect pressure but to other biological processes inside young rice seedlings as they are affected by the presence of the insecticide. In 2011, an observation was made by Gus Lorenz, State Extension Entomologist, University of Arkansas, that some of his insecticide treated rice was able to tolerate an accidental herbicide drift from an adjacent field (pers. comm.). The ability to safen rice to potential herbicide drift or injury from other herbicides would be a valuable tool for rice producers today. This seems to be especially true as seeding rates are lowered for many rice varieties and hybrids. In 2013, an initial study indicated that the use of CruiserMax rice seed treatment could prevent some crop response from low doses of both Newpath and glyphosate herbicides (Dickson et. al., 2014).

The objective of this research was to confirm across years the potential for Cruiser Maxx Rice insecticide seed treatment to protect conventional rice (Roy J) from both Newpath and Roundup exposure.

PROCEDURES

This experiment was conducted at the University of Arkansas at Pine Bluff Research Farm located just north of Lonoke, Ark., in the summers of 2013 and 2014. The soil texture is a silt loam with a pH of 6.3. Conventional rice (Roy J) was seeded on 31 April 2013 and on 20 May 2014 with a Hege cone-drill calibrated to deliver a seeding rate of 90 lb/acre on 7.5-inch-spaced rows. Plot size was 5 ft × 25 ft. The study was conducted with a randomized complete block design having four replications.

Treatments consisted of seed treatment and herbicide combinations. The seed treatments consisted of a "treated seed" on which Cruiser Maxx Rice at 7 oz/100 lb of seed was applied. Cruiser Maxx Rice contains 26.4% thiamethoxam, 1.65% mefenoxam, 1.32% azoxystrobin, and 0.28% fludioxonil. The second seed treatment was considered the "nontreated seed" which actually was seed treated with the equivalent amounts of azoxystrobin, mefenoxam, and fludioxonil minus the insecticide thiamethoxam.

The herbicide treatments were applied at the 2- to 3-lf growth stage of rice with a CO_2 backpack sprayer calibrated to deliver 10 gallons of spray solution per acre. Herbicide treatments included Roundup PowerMax (5.5 lb ai/gal formulation) applied at 0, 1, 2, and 4.0 fl oz product/acre and Newpath 2AS (2 lb ai/gal formulation) applied at 0, 0.25, 0.5 and 1.0 fl oz product/acre. The plot area was maintained weed free with conventional rice herbicides, and the rice was grown according to University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations for soil fertility.

Data collected included percent visible injury at 7, 21, and 42 days after treatment (DAT) on a scale of 0 to 100 with 0 being no injury and 100 being complete crop death; canopy heights at 68 DAT using a yard stick and a 1 meter square piece of cardboard as described by Davis et al. (2011), percent rice heading at 107 DAT, and percent moisture and grain yield at harvest. Data were analyzed and Fisher's least significant difference test was performed at $P = 0.05$ level of significance using Agricultural Research Manager (ARM) v. 9.1.4 (Gylling Data Management, Inc., Brookings, S.D.).

RESULTS AND DISCUSSION

As early as 7 DAT, both Newpath and Roundup were causing visible injury to rice (Table 1). Plants grown from the nontreated rice seed were injured by Roundup from 15% to 25% and from treated seed 11% to 17% depending on rate. Newpath at 7 DAT also caused injury ranging from 5% to 24% depending on rate and whether the seed was treated or not. Injury from Newpath was already visibly less on rice plants with the seed treatment 7 DAT, especially at 0.50 and 0.25 fl oz/acre, where rice was injured nine to ten percentage points less when seed was treated with the insecticide thiamethoxam in the form of Cruiser Maxx Rice averaged over 2 years. Injury symptoms included stunting and chlorosis (yellowing).

By 21 DAT, injury symptoms had become more pronounced for all Newpath treatments. Rice plants from treated and nontreated seed were injured over 50% by Newpath at 1.0 fl oz/acre. However, some differences were also becoming more pronounced by 21 DAT. For example, where Newpath at 0.5 fl oz/acre was applied to rice plants grown from nontreated seed it injured rice 36% versus only 13% for treated seed. Roundup at 4 fl oz/acre injured rice with treated seed 12 percentage points less than when seed was nontreated.

In 2014, rice injury was reduced to less than 10% for all treatments (data not shown). However in 2013, injury had been equal for Newpath applied at 1 fl oz/acre to rice from both treated and nontreated seed at 21 DAT. In 2013, rice plants from treated seed had recovered by 42 DAT and injury for treated versus nontreated was 58% and

97%, respectively (Table 1). Other herbicide seed treatment interactions were even more pronounced at 42 DAT. Newpath applied at 0.25 fl oz/acre caused no visible injury to rice with treated seed; whereas, 26% injury was observed in nontreated rice. Injury from this rate of Newpath to plants grown from nontreated rice seed was consistently rated at 25% for the duration of the test. At 0.5 fl oz/acre rate of Newpath, injury to rice grown from the treated seed had dropped to 6%, versus 63% for rice where the seed was nontreated. Roundup applied at 4 fl oz/acre resulted in 53% injury to the rice plants with the nontreated seed versus only 10% when rice seed was treated. The later planting date and warmer, sunnier growing conditions in 2014 versus 2013 may account for differences in rice recovery between years.

Canopy heights were not affected by any treatments in 2014 (data not shown). Treatment differences were observed in canopy height taken at 68 DAT in 2013 (Table 1). Rice plants that did not receive any herbicide treatment, regardless of seed treatment grew to a canopy height of 35 inches. Newpath reduced canopy height at the 0.5 and 1.0 fl oz/acre rates when applied to rice with non-insecticide treated seed. There were not enough rice plants in the 1.0 fl oz/acre Newpath treatment to get a canopy height due to severe stand reduction in the absence of the insecticide seed treatment. However, the rice with treated seed survived the 1.0 fl oz/acre of Newpath and resulted in a canopy height of 30 inches, not statistically different from the check (35 inches).

Roundup in general did not affect canopy height as severely as Newpath (Table 1). Both insecticide treated and nontreated rice seed produced plants with canopy heights from 32 to 38 inches when 1 or 2 fl oz/acre of Roundup were applied with no statistical difference from the nontreated check. However at the 4 fl oz/acre rate of Roundup, the rice with nontreated seed grew to 23 inches while the rice with treated seed reached a normal height similar to the check of 36 inches by 68 DAT.

Percent heading, harvest moisture, and grain yield were obtained at 107 DAT in both years of this study. However no significant differences in heading or moisture were observed in 2014 (data not shown). For purposes of this study, a common harvest date was selected to simulate a decision that a grower might have to make as to when to harvest a field with varying degrees of injury. For this reason the above mentioned harvest parameters might have been slightly different if, for example, some of the more severely injured rice was given more time to mature and dry down. Likewise, the less injured rice could have been harvested sooner. However, due to study design this was not practical. Therefore, a single harvest date was chosen based on a time when the majority of rice was mature. In 2014, almost all treatments resulted in a uniform maturity and harvest date; one possible exception was the 1 fl oz/acre rate of Newpath on nontreated rice. This difference was evident only in the grain yield results.

Percent heading was taken as a visual rating based on the non-herbicide treated checks which were both 100% headed at 107 DAT in 2013 (Table 1). The only rice that received an insecticide seed treatment and had delayed heading was when 1 fl oz/acre Newpath was applied which reduced heading about 40% compared to the check. All rice that received the insecticide thiamethoxam in the seed treatment resulted in 95% to 100% heading at the time evaluated. Newpath generally delayed heading or prevented heading to a more severe degree than Roundup on nontreated seed plants. Newpath at

0.25, 0.5, and 1 fl oz/acre resulted in 20%, 42%, and 52% reductions in rice heading, respectively, at 107 DAT on rice grown from nontreated seed.

At harvest, grain yield and percent moisture was determined for each treatment. There was a tremendous amount of variation among the herbicide treated rice which resulted in few statistical differences. The non-herbicide treated checks were at 22% moisture at harvest time in 2013 (data not shown). With a least significant difference of 8% moisture, few of the treatment differences were significant. Results like these can be common when dealing with rates of herbicides applied far below the labeled rates (Davis et al., 2011; Hensley et al., 2012). Again in 2014, harvest and maturity of all treatments were much more uniform than in 2013.

Due to a significant interaction between years, yield results are presented by year (Table 1). In 2013, grain yield of rice ranged from 17 to 170 bu/acre with a least significant difference (0.05) of 25 bu/acre for this experiment. Rice plants grown with non-treated rice seed and no herbicide yielded 147 bu/acre while the insecticide treated check yielded 169 bu/acre. When Newpath herbicide was applied at either 0.25 or 0.5 fl oz/acre to rice grown from seed treated with thiamethoxam resulting yields were ~100 bu/acre higher compared to rice grown with nontreated or fungicide-only treated seed. However, at the 1 fl oz/acre rate of Newpath even the rice with treated seed yielded only 45 bu/acre compared to 17 bu/acre for rice with non-treated seed. These results suggest that there is a limit to thiamethoxam's ability to "safen" rice to Newpath. In 2013, all treatments with insecticide treated rice seed yielded higher than non-treated rice seed when exposed to Roundup (Table 1). This difference was most pronounced at the 4 fl oz/acre rate of Roundup where yield was improved by 69 bu/acre with the addition of a seed treatment that included thiamethoxam.

No major differences in yield were observed in 2014 (Table 1). However, rice grown from nontreated seed yielded 194 bu/acre when Newpath was applied at 1.0 fl oz/acre and 197 bu/acre when 0.5 fl oz/acre of Newpath was applied. The treated-seed check yielded significantly higher at 231 bu/acre.

SIGNIFICANCE OF FINDINGS

The ability of a seed treatment to enable young rice plants to better tolerate off-target drift of both Newpath and Roundup could significantly reduce the number of complaint investigations requested by growers to both the Arkansas State Plant Board and the Cooperative Extension Service. The resulting higher yields (2013) as rice injury was reduced are not only a benefit to growers, but also to those responsible for the off-target movement. This research does confirm the results observed in 2013 even though the response to the seed treatment was not as great in 2014. Although more research is needed, the potential ability of an insecticide seed treatment to improve tolerance of certain Clearfield hybrid varieties such as XL745 would be of benefit under cool, wet conditions especially with reduced seeding rates. Approximately 50% of rice grown in Arkansas is Clearfield. Findings from this research could enable growing Clearfield and non-Clearfield varieties in closer proximity to each other more plausible and less troublesome to applicators and growers. Other applications of this new discovery are currently being evaluated.

ACKNOWLEDGMENTS

Special appreciation is extended to the Rice Research and Promotion Board for providing funding and support for this project.

LITERATURE CITED

Culpepper, A.S., A.C. York, J.L. Marth, and F.T. Corbin. 2001. Effect of insecticides on clomazone absorption, translocation, and metabolism in cotton. Weed Sci. 49:613-616.

Davis, B.M., R.C. Scott, J.K. Norsworthy, and E. Gbur. 2011. Response of rice to low rates of glyphosate and glufosinate. Weed Technol. 25:198-204.

Dickson, J.W., R.C. Scott, and B.M. Davis. 2014. Response of the conventional rice varieties Roy J and Wells to low soil concentrations of Imazethapyr. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:206-211. Fayetteville, Ark.

Hardke, J.T. and C.E. Wilson Jr. 2012. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 609:38-47. Fayetteville, Ark.

Hensley, J.B., E.P. Webster, D.C. Blouin, D.L. Harrell, and J.A. Bond. 2012. Impact of drift rates of imazethapyr and low carrier volume on non-Clearfield Rice. Weed Technol. Vol. 26:236-242.

Plummer, W.A., G.M. Lorenz III, N.M. Taillon, B.C. Thrash, J.W. Fortner, and C.K. Colwell. 2012. Impact of insecticide seed treatments in large block field trials in Arkansas 2009-2011. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:128-131. Fayetteville, Ark.

Wilf, H., G.M. Lorenz, III, K. Colwell, and N. Taillon. 2010. Comparing the efficacy of insecticide seed treatments at three seeding rates. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:104-108. Fayetteville, Ark.

Wilson, C.E. Jr., S.K. Runsick, and R. Mazzanti. 2010. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:11-21. Fayetteville, Ark.

York, A.C. and D.L. Jordan. 1992. Cotton response to clomazone and insecticide combinations. Weed Technol. 6:796-800.

York, A.C., D.L. Jordan, and R.E. Frans. 1991. Insecticides modify cotton (*Gossypium hirsutum*) response to clomazone. Weed Technol. 5:729-735.

Table 1. Effect of Newpath and Roundup at reduced rates on rice injury, plant canopy height, heading date, percent grain moisture and yield when applied to insecticide treated versus untreated Roy J rice seed at the University of Arkansas at Pine Bluff Farm, near Lonoke, Ark., in 2013 and 2014, averaged across years when possible (P = 0.05).

Treatment	Herbicide rate	Visible injury 2013-14 7DAT	Visible injury 2013-14 21DAT	Visible injury 2013 42DAT	Height 2013 68DAT	Heading 2013 107DAT	Grain yield 2013	Grain yield 2014
	(fl oz/acre)	(%)	(%)	(%)	(in.)	(%)	(bu/acre)	(bu/acre)
Treated	0	0	0	0	35	100	169	231
Nontreated Newpath	0.25	15	16	26	30	80	170	229
Treated Newpath	0.25	5	6	0	36	100	70	216
Nontreated Newpath	0.50	24	36	63	21	58	136	197
Treated Newpath	0.50	16	13	6	32	95	37	211
Nontreated Newpath	1.0	24	61	97	--	48	45	194
Treated Newpath	1.0	17	51	58	30	63	17	220
Nontreated Roundup	1.0	17	15	13	38	83	104	198
Treated Roundup	1.0	12	13	0	35	98	148	218
Nontreated Roundup	2.0	15	17	11	32	90	113	211
Treated Roundup	2.0	11	9	0	34	95	144	219
Nontreated Roundup	4.0	25	28	53	23	78	59	221
Treated Roundup	4.0	25	16	10	36	95	128	221
LSD (P = 0.05)		8	10	21	8	9	25	30

First Report of Acetolactate Synthase-Resistant Yellow Nutsedge in Arkansas Rice: Confirmation and Control

P. Tehranchian, J.K. Norsworthy,
M.V. Bagavathiannan, D.S. Riar, M.T. Bararpour, and R.C. Scott

ABSTRACT

Yellow nutsedge is a troublesome perennial weed in rice and soybean rotations throughout the Mississippi Delta region. Yellow nutsedge plants originating from tubers collected from a rice field in eastern Arkansas were confirmed resistant to halosulfuron (Permit). The resistant biotype was >133 fold less responsive to halosulfuron than a susceptible biotype. It was cross resistant to the acetolactate synthase (ALS)-inhibiting herbicides imazamox (Beyond), imazethapyr (Newpath), bispyribac-sodium (Regiment), pyrithiobac (Staple LX), bensulfuron (Londax), and penoxsulam (Grasp). These six ALS-inhibiting herbicides comprise four different chemical families. Control of the resistant biotype with the labeled field rate of quinclorac (Facet), bentazon (Basagran), propanil (Super Wham), and 2,4-D (Weedar) was ≤40%, and control with glyphosate (Roundup PowerMax) was only 67%. This study indicates that the ALS-resistant yellow nutsedge biotype is cross resistant to a broad array of ALS inhibitors and the alternative herbicides tested here will not provide complete control of the resistant biotype.

INTRODUCTION

Yellow nutsedge (*Cyperus esculentus* L.) is a major weed in irrigated crops and vegetables worldwide (Holm et al., 1991) and it is one of the most common and troublesome weeds of Arkansas rice (Norsworthy et al., 2013; Scott et al., 2014a). It infests croplands with extensive rhizome proliferation and tuber production (Horak and Holt, 1986) which are the key cause of its dispersal by tillage equipment (Schippers et al., 1993). Tuber dormancy in yellow nutsedge lessens over the winter and most tubers usually sprout the following spring (Stoller and Wax, 1973). Commercialization of Clearfield rice technology in 2002 has allowed farmers to frequently use acetolactate synthase (ALS)-inhibiting herbicides to control sedges, grasses, and broadleaf weeds in an Arkansas rice-soybean production system (Norsworthy et al., 2007). Of the ALS-inhibiting herbicides available in Arkansas rice, imazosulfuron (League) applied pre-emergence (PRE) and Permit applied post-emergence (POST), effectively control yellow nutsedge.

In the summer of 2012, lack of control of a novel nutsedge occurred in a rice field near Hoxie, Ark., following a labeled application of halosulfuron. Charles Bryson, a plant taxonomist with USDA likewise identified the weed as yellow nutsedge (hereafter, Res). The Res biotype showed phenotypic differences with extensive subterranean distribution and ground coverage compared to the very dense growth of the susceptible biotype (hereafter, Sus) (Fig. 1). The Res biotype produces dark purplish brown colored tubers whereas the Sus biotype has tubers that are yellow beige. The Res biotype was not controlled in an initial greenhouse screen that included higher than labeled rates. Hence, a greenhouse experiment was conducted to assess the level of resistance to halosulfuron and to evaluate cross resistance to other ALS-inhibiting herbicides across four unique chemical families. Additionally, other herbicide options that are currently labeled for use in rice or in soybean (Scott et al., 2014b) were evaluated as alternatives for controlling the Res biotype.

PROCEDURES

The greenhouse experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center, Fayetteville, Ark. Tubers from the Res biotype were collected from the infested field and clonally propagated in the greenhouse. Tubers of a known Sus were collected from a rice field near Stuttgart, Ark. Tubers of both biotypes were sprouted individually in plastic trays (55.5 × 26.5 × 5.5 cm^3) filled by commercial quality potting mix and subsequently transplanted into plastic pots (15 cm diameter × 12 cm high) at the 3- to 4-lf stage. All herbicide treatments were applied to 4- to 5-lf plants. An automated sprayer fitted with a boom containing two flat fan 80067 nozzles was calibrated to deliver 20 gal/acre of herbicide solution at 40 PSI. Treated plants were maintained in the greenhouse at 86/68 °F day/night temperature under a 14-h photoperiod and watered on a daily basis.

The dose response experiment was conducted as a randomized complete block design (RCBD) with 20 replications per dose and was repeated. Rates of halosulfuron applied to the Sus biotype were 0.0625, 0.125, 0.25, 0.5, 1, 2, 4, and 8× the recommended field rate of 0.047 lb ai/acre. The resistant biotype was treated with halosulfuron at 4, 8, 16, 32, 64, 128, and 256× the recommended field rate. All herbicide solutions contained 1% v/v crop oil concentrate. Mortality data were recorded 28 days after treatment (DAT). Data were subjected to probit analysis using PROC PROBIT in SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.) to determine the lethal dose (LD) required to kill 50% (LD_{50}) and 90% (LD_{90}) of the treated plants.

Both cross resistance and alternative herbicide evaluation experiments were conducted in a RCBD with both biotypes (Res and Sus). The evaluated herbicides and rates are shown in Table 1. Both experiments were replicated four times and repeated. Control was visually rated 28 DAT on a 0 (no injury) to 100 (dead plants) scale. Subsequently shoot biomass was oven dried at 140 °F for 48 h and dry weight was recorded. Data were subjected to analysis of variance (ANOVA) using PROC MIXED in SAS (SAS Institute, Inc., Cary, N.C.). Means were separated using Fisher's protected least significant difference test at $P = 0.05$.

RESULTS AND DISCUSSION

Dose Response Study

Even the highest rate of halosulfuron did not kill any plants originating from the Res biotype. Based on LD_{50} resistance ratio values, the Res biotype was >134 fold less sensitive to halosulfuron than the Sus biotype (Table 2), indicating a high level of resistance that usually corresponds to an altered target site (Heap, 2014). The relatively high LD_{90} value of the Sus biotype relative to the 1× rate points to the difficulty in achieving complete control of yellow nutsedge with halosulfuron. Under field conditions, several herbicide applications are often needed to achieve a high level of season-long control.

Cross Resistance Study

Response of the Res and Sus biotypes to ALS-inhibiting herbicides is shown in Fig. 2. All ALS-inhibiting herbicides tested here effectively controlled the Sus biotype. Growth reduction of the Sus biotype ranged from 72% to 97% across the ALS-inhibiting herbicides evaluated. On the contrary, growth reduction of the Res biotype was ≤16% for the same herbicides, indicating cross resistance has evolved across four unique chemical families. Cross resistance to ALS-inhibiting herbicides has been reported in other closely related species such as smallflower umbrella sedge (Tehranchian et al., 2015).

Alternative Herbicides

A labeled rate of propanil (Super Wham), bentazon (Basagran), quinclorac (Facet), and 2,4-D (Weedar) controlled the Res and Sus biotypes ≤40% and ≤60%, respectively. Glyphosate (Roundup PowerMax) provided 67% control of the Res biotype which was significantly less than the 95% control that resulted from the same treatment on the Sus biotype (Fig. 3). Complete control (100%) of the Res biotype was achieved when glyphosate was applied at twice the labeled use rate (data not shown).

SIGNIFICANCE OF FINDINGS

This is the first known occurrence of herbicide resistance in yellow nutsedge worldwide. Practicing of integrated weed management strategies such as rice rotation with soybean where herbicides such as glyphosate and metolachlor can be used to provide a high level of control is recommended (Felix and Newberry, 2012). However, greater effort must be placed on adding diverse weed control strategies into current yellow nutsedge management strategies if the use of herbicides for controlling this weed is to be sustained. Furthermore, this research points to the need for additional effective herbicide options in rice.

ACKNOWLEDGMENTS

We are thankful to the Arkansas Rice Promotion Board for funding this research.

LITERATURE CITED

Felix J. and G. Newberry. 2012. Yellow nutsedge control and reduced tuber production with S-metolachlor, halosulfuron plus dicamba, and glyphosate in furrow-irrigated corn. Weed Technol. 26:213-2019.

Heap, I. 2014. International Survey of Herbicides Resistant Weeds, Accessed 11 February 2014. Available from: http://www.weedscience.org

Holm, L.G., J.V. Plucknett, J.V. Pancho, and J.P. Herberger. 1991. The world's worst weeds. Kriegar Publishing Company, Malabar, Fla.

Horak, M.J. and J.S. Holt. 1986. Isozyme variability and breeding systems in populations of yellow nutsedge (*Cyperus esculentus*). Weed Sci 34:538-543.

Norsworthy J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623-630.

Norsworthy, J.K., N.R. Burgos, R.C. Scott, and K.L. Smith. 2007. Consultant perspectives on weed management needs in Arkansas rice. Weed Technol. 21:832-839.

Schippers P., S.J.T. Borg, J.M. Van Groenendael, and B. Habekotte. 1993. What makes *Cyperus esculentus* (yellow nutsedge) an invasive species? A spatial model approach. pp 495-504. *In:* Proc. Brighton Crop Protection Conference-Weeds. Hampshire, U.K.: British Crop Protection Council.

Scott R.C., J.W. Boyd, G. Selden, J.K. Norsworthy, and N.R. Burgos. 2014a. Recommended chemicals for weed and brush control-MP44. University of Arkansas Cooperative Extension Service Publication, Fayetteville, Ark. Pp 79.

Scott R.C., J.K. Norsworthy, and M. Bagavathiannan. 2014b. Identification and control of problematic sedges in Arkansas rice. University of Arkansas Extension-Agriculture and Natural Resources Fact Sheet no. FSA2173. Available from: http://www.uaex.edu/publications/pdf/FSA-2173.pdf

Stoller E.W. and L.M. Wax. 1973. Yellow nutsedge shoot emergence and tuber longevity. Weed Sci. 21:76-81.

Tehranchian P., D.S. Riar, J.K. Norsworthy, V. Nandula, S. McElroy, S. Chen, and R.C. Scott. 2015. ALS-resistant smallflower umbrella sedge (*Cyperus difformis*) in Arkansas rice: Physiological and molecular basis of resistance. Weed Sci. (In press).

Table 1. Description of herbicide treatments used in acetolactate synthase (ALS)-inhibitors cross resistance and alternative herbicide studies.

Common name	Trade name	Labeled field rate	Adjuvant
		(fl oz/acre)	(% v/v)
ALS-inhibiting herbicides			
Imazamox	Beyond	5	1% COC[a]
Imazethapyr	Newpath	6	0.25% NIS[b]
Bispyribac-sodium	Regiment	0.63	0.75% NIS[c]
Pyrithiobac	Staple LX	2.1	---
Halosulfuron	Permit	1	1% COC
Bensulfuron	Londax	1.67	1% COC
Penoxsulam	Grasp	2.3	1% COC
Alternative rice herbicides			
2,4-D	Weedar 64	32	0.25% NIS
Bentazon	Basagran	32	---
Glyphosate	Roundup PowerMax	32	---
Quinclorac	Facet	43	---
Propanil	Super Wham	128	---

[a] COC = crop oil concentrate.
[b] NIS = nonionic surfactant.
[c] Dyne-A-Pak = blend of nonionic spray adjuvant and deposition aid.

Table 2. Determination of level of resistance to halosulfuron in acetolactate synthase (ALS)-resistant yellow nutsedge.

Biotype	LD_{50}[a]	LD_{50} (Res/Sus)	LD_{90}[a]	LD_{90} (Res/Sus)
	(lb ai/acre)		(lb ai/acre)	
Resistant (Res)	>12.08	>134	>12.08	>134
Susceptible (Sus)	0.09		2.18	

[a] LD_{50} and LD_{90} = lethal dose (LD) of herbicide required to kill 50% and 90% of plants, respectively.

Fig. 1. Spatial distribution of acetolactate synthase (ALS)-inhibitor-resistant (left) and susceptible yellow nutsedge (right) biotypes at 50 days after emergence.

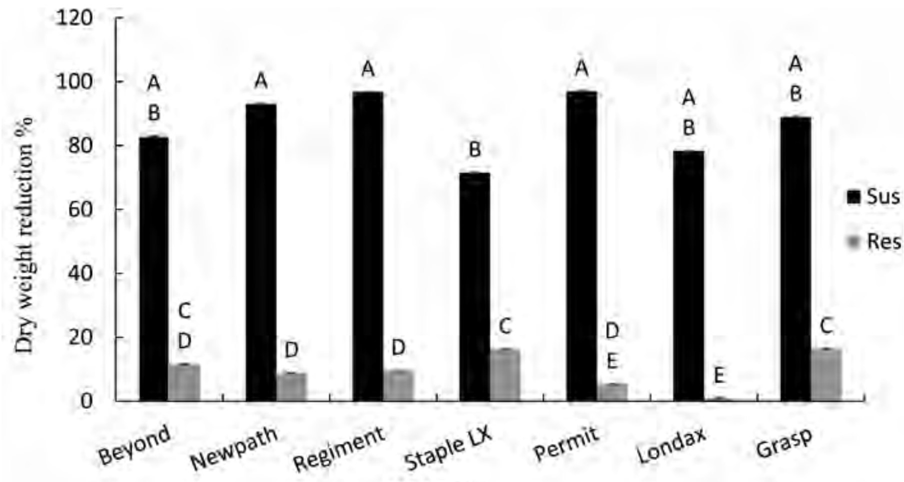


Fig. 2. Shoot biomass dry weight reduction (%) of yellow nutsedge susceptible (Sus) and resistant (Res) biotypes in response to acetolactate synthase (ALS)-inhibitors. Means followed by different letters are significantly different at *P* = 0.05.

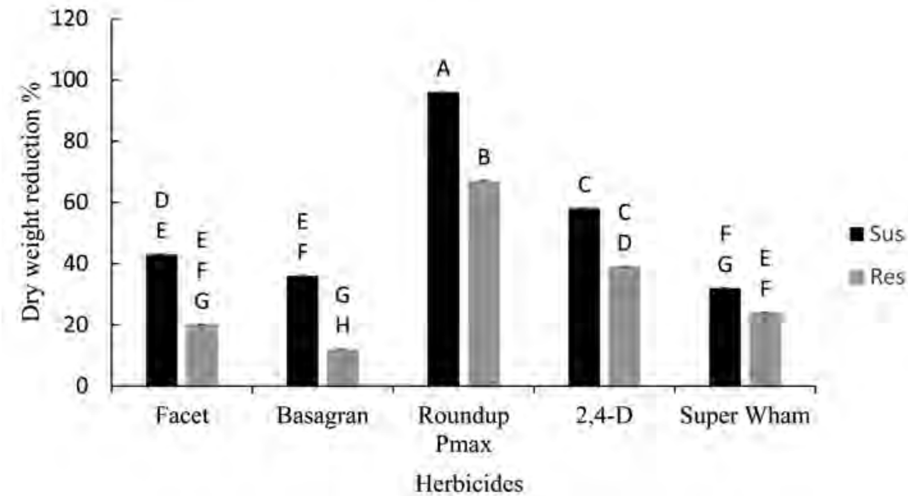


Fig. 3. Shoot biomass dry weight reduction (%) of yellow nutsedge susceptible (Sus) and resistant (Res) biotypes in response to alternative rice-soybean herbicide options. Means followed by different letters are significantly different at *P* = 0.05.

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2014

E. Castaneda-Gonzalez, D.L. Frizzell, J.T. Hardke, Y.A. Wamishe, and R.J. Norman

ABSTRACT

On-farm testing provides researchers with the best opportunity to evaluate the performance of cultivars under diverse production conditions. By placing trials throughout the state under varied production management conditions, more accurate performance evaluations can be made for grain yield, milling quality, and profit. These trials also provide an accurate representation of cultivar performance across environmental conditions and soil types in a wide range of fertility, weed, pest, and disease management practices. Proper cultivar selection is the most important decision a producer makes since it can reduce production costs and increase profits for the grower by minimizing problems associated with cultivars less suited to a particular growing situation. Hence, performance evaluations accounting for the range of previously listed factors are necessary for overall cultivar selection. The Producer Rice Evaluation Program (PREP) utilizes studies in production fields with commercial cultivars and experimental lines to evaluate disease, lodging, grain yield potential, and milling quality under various environmental and cultural management conditions found in Arkansas.

INTRODUCTION

The goal of the University of Arkansas System Division of Agriculture's Cooperative Extension Service is to offer a complete production package to producers when southern U.S. rice cultivars are released, including grain and milling yield potential, disease reactions, fertilizer recommendations, and Degree-Day 50 (DD50) computer program thresholds. Many factors can influence grain yield potential including: seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice diseases are an important constraint to profitable rice production in Arkansas. To reduce disease potential, we recommend the use of host-plant resistance, optimum cultural practices, and fungicides (only when necessary) based on integrated pest management (IPM) practices for disease control. The use of resistant cultivars, combined with optimum cultural practices, provide growers with the opportunity to maximize profit at the lowest disease control expenditure by avoiding the use of costly fungicide applications.

New rice cultivars are developed and evaluated each year at the University of Arkansas System Division of Agriculture under controlled experiment station conditions. A large set of data on grain yield, grain quality, plant growth habit, and major disease resistance is collected during this process. Unfortunately, the dataset under these conditions is not complete for many of the environments where rice is grown in Arkansas because potential problems may not be evident in nurseries grown on experiment stations. With information obtained from field research coupled with knowledge of a particular field history, growers can select the cultivar that offers the highest yield potential for their particular situation. Ongoing field research is necessary to generate this knowledge. The Producer Rice Evaluation Program (PREP) was designed to better address the many risks faced by newly released cultivars across the rice-growing regions of Arkansas. The on-farm evaluation of new cultivars provides better information on disease development, lodging, grain yield potential, and milling yield under an array of environmental conditions and crop management practices that exist in Arkansas. These studies also provide a hands-on educational opportunity for county agents, consultants, and producers.

The objectives of the PREP include: 1) to compare the yield potential of commercially available cultivars and advanced experimental lines under commercial field production conditions, 2) to monitor disease pressure in the different regions of Arkansas, and 3) to evaluate the performance of rice cultivars to conditions not commonly observed on experiment stations.

PROCEDURES

Field studies were located in Chicot, Conway, Craighead, Crittenden, Greene, Phillips, Poinsett, and Prairie counties during the 2014 growing season. Nineteen cultivars were selected for evaluation in the on-farm tests. Entries selected for each location along with the corresponding seeding date are shown in Table 1. Non-Clearfield entries evaluated during 2014 included Antonio, Caffey, Jazzman-2, Jupiter, LaKast, Mermentau, Roy J, Taggart, two University of Arkansas experimental lines (UAEX1021 and UAEX1084), and the RiceTec hybrid XL753. Clearfield lines included CL111, CL151, CL152, CL163, CL172, CL271, and the RiceTec hybrids CLXL729 and CLXL745.

Plots were 8 rows (7-in. spacing) wide and 16-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of approximately 30 seed/ft^2 while hybrids were seeded at a rate of approximately 14 seed/ft^2. Trials were seeded on 11 April (Conway), 21 April (Chicot), 23 April (Greene and Poinsett), 24 April (Crittenden and Phillips), and 8 May (Prairie). Since these experiments contain both Clearfield and non-Clearfield entries, all plots were managed as non-Clearfield cultivars. Plots were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. The dried rice was milled to obtain percent head rice and percent total white rice (%HR-%TR). Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

All cultivars were represented at all locations during the 2014 growing season; a summary of the results by county and corresponding date of seeding is presented (Table 1). Across counties, the grain yield averaged 207 bu/acre. Ricetech XL753 and Jupiter were the highest-yielding cultivars followed by Caffey and LaKast. In the Chicot Co. trial (Table 2), the grain yield average of all the rice entries was 190 bu/acre. The highest yielding cultivars were RTXL753, RTCLXL729, Caffey, and Jupiter. In the Conway Co. trial (Table 3), grain yield for the location averaged 165 bu/acre, the lowest of all the counties during 2014. The highest yielding cultivars were Jupiter, Roy J and RTXL753. Jupiter, and RTXL753 were the highest yielding cultivars in the Craighead Co. trial (Table 4). In the Crittenden Co. trial (Table 5), RTXL753, RTCLXL729, and RTCLXL745 were the highest yielding cultivars producing grain yields of 239 bu/acre or greater. Ricetech XL753 was the highest yielding cultivar (280 bu/acre) in the Greene Co. trial (Table 6) followed by LaKast and Caffey. In the Phillips Co. trial (Table 7), RTXL753, RTCLXL745, and RTCLXL729 were the highest yielding cultivars with grain yields of 209 bu/acre or more. The Poinsett Co. trial (Table 8) recorded the highest grain yield average of all locations at 246 bu/acre, with CL111, Jupiter, RTXL753, CL151, and RTCLXL745 having the highest grain yields of 265 to 269 bu/acre. In Prairie Co. (Table 9), the latest-planted PREP trial in 2014, the overall grain yield of 205 bu/acre was greater than some earlier-planted trials (Conway and Chicot counties). The highest yielding cultivars at Prairie Co. were Jupiter, Caffey, RTXL753, Taggart, and CL151. Monitoring cultivar response to disease presence and the incidence and severity of reactions is a significant part of this program. The observations obtained from these plots are often the basis for disease ratings developed for use by growers (Table 10). This is particularly true for minor diseases that may not be encountered frequently, such as narrow brown leaf spot, false smut, and kernel smut.

Yield variability among the study sites represents differences in environments and management practices, but also susceptibility to lodging and disease pressure present at individual locations.

SIGNIFICANCE OF FINDINGS

The 2014 Producer Rice Evaluation Program (PREP) provided additional data to the rice breeding and disease resistance programs. The program also provided supplemental performance and disease reaction data on new cultivars that will be more widely grown in Arkansas during 2015.

ACKNOWLEDGMENTS

The authors appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. The authors especially thank the following county agents who made this work possible: Dave Freeze, Robert Goodson, Brent Griffin, Mike Hamilton, Russ Parker, Branon Theisse, Kevin Van Pelt, and Gus Wilson.

This page left blank intentionally to facilitate the following tables.

Table 1. Results of the Producer Rice Evaluation

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Milling yield	Chicot 4/21	Conway 4/11
		(%)		(lb/bu)	(HR-TR)	------------------------------	
Antonio	L	0.0	16.3	44.6	66-70	129	104
Caffey	M	0.0	17.3	47.1	63-70	223	196
CL111	L	3.5	15.0	44.4	63-70	153	143
CL151	L	7.5	15.9	44.5	63-69	181	146
CL152	L	0.0	15.9	44.4	63-68	175	141
CL163	L	0.0	15.8	44.4	63-68	169	156
CL172	L	0.0	16.7	45.3	65-70	192	166
CL271	M	0.0	16.4	45.3	63-70	181	165
Jazzman-2	L	0.0	16.6	42.9	61-66	137	52
Jupiter	M	3.0	18.2	48.2	63-69	220	217
LaKast	L	3.1	15.2	44.5	62-70	209	181
Mermentau	L	0.0	16.5	44.4	64-68	169	174
Roy J	L	0.0	17.0	42.6	63-70	209	200
RTCLXL729	L	1.9	14.7	41.6	64-70	215	167
RTCLXL745	L	0.0	14.6	40.9	61-70	185	166
RTXL753	L	0.0	15.0	41.9	60-70	227	199
Taggart	L	0.0	16.8	45.8	62-70	201	189
AREX1021	M	0.3	16.5	47.8	62-71	224	216
AREX1084	L	0.0	17.0	44.4	63-69	215	--
MEAN	--	1.0	16.2	44.5	63-69	190	165
LSD	--	5.5	1.9	0.8	--	25.2	23.6

[a] Grain length: L = long grain; M = medium grain.

Program (PREP) at eight locations during 2014.

Grain yield by location and planting date						
Craighead 4/21	Crittenden 4/24	Greene 4/23	Phillips 4/24	Poinsett 4/23	Prairie 5/8	MEAN
(bu/acre)						
--	195	222	145	215	189	171
246	217	250	182	234	224	222
180	202	221	169	269	178	189
225	184	242	173	265	219	205
185	207	222	160	230	196	190
223	185	234	143	241	196	193
195	204	240	160	232	198	198
238	178	232	140	249	196	197
--	188	211	128	220	163	157
286	228	272	183	268	241	239
252	205	258	189	253	212	220
190	197	224	171	225	199	194
240	176	230	169	217	206	206
230	245	213	209	255	212	218
231	239	220	217	265	202	216
267	263	280	223	268	220	243
234	210	242	186	247	219	216
246	241	270	179	281	225	235
241	195	--	--	--	--	217
230	208	238	174	246	205	207
26.8	29.0	26.9	15.9	22.0	15.6	21.0

Table 2. Results of Chicot County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	14.6	44.5	129	57-68
Caffey	M	0.0	17.3	47.4	223	68-72
CL111	L	0.0	13.8	44.5	153	59-68
CL151	L	0.0	14.3	44.9	181	57-70
CL152	L	0.0	14.6	45.0	175	59-70
CL163	L	0.0	14.8	44.3	169	61-68
CL172	L	0.0	15.4	45.4	192	66-71
CL271	M	0.0	16.0	45.0	181	68-72
Jazzman-2	L	0.0	14.7	43.5	137	53-67
Jupiter	M	0.0	18.7	49.2	220	67-71
LaKast	L	0.0	14.6	44.7	209	60-70
Mermentau	L	0.0	14.7	44.3	169	64-69
Roy J	L	0.0	14.9	43.6	209	64-71
RTCLXL729	L	0.0	13.9	41.6	215	59-70
RTCLXL745	L	0.0	13.2	40.6	185	53-69
RTXL753	L	0.0	14.6	41.9	227	57-70
Taggart	L	0.0	15.1	46.0	201	58-70
AREX1021	M	0.0	16.1	48.3	224	63-71
AREX1084	L	0.0	15.7	45.1	215	60-70
MEAN	--	0.0	15.1	44.7	10	61-70
LSD	--	0.0	1.0	1.0	25.2	--

[a] Grain length: L = long grain; M = medium grain.

Table 3. Results of Conway County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	15.9	43.3	104	65-68
Caffey	M	0.0	17.0	47.1	196	66-70
CL111	L	0.0	14.5	43.8	143	66-70
CL151	L	0.0	14.9	44.3	146	66-69
CL152	L	0.0	14.7	43.9	141	65-69
CL163	L	0.0	14.8	43.3	156	64-68
CL172	L	0.0	15.3	43.5	166	66-69
CL271	M	0.0	15.9	44.8	165	67-70
Jazzman-2	L	0.0	16.0	40.5	52	62-65
Jupiter	M	0.0	18.9	47.6	217	64-69
LaKast	L	0.0	14.2	43.5	181	66-71
Mermentau	L	0.0	15.6	43.8	174	65-68
Roy J	L	0.0	14.2	42.7	200	65-71
RTCLXL729	L	0.0	14.2	41.7	167	67-70
RTCLXL745	L	0.0	14.8	40.9	166	64-70
RTXL753	L	0.0	14.5	41.6	199	63-70
Taggart	L	0.0	16.0	44.8	189	65-70
AREX1021	M	0.0	16.6	46.9	216	67-70
AREX1084	L	--	--	--	--	--
MEAN	--	0.0	15.4	43.8	165	65-69
LSD	--	0.0	0.9	0.9	23.6	--

[a] Grain length: L = long grain; M = medium grain.

Table 4. Results of Craighead County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	--	--	--	--	--
Caffey	M	0.0	13.9	47.2	246	60-71
CL111	L	0.0	13.6	44.8	180	60-70
CL151	L	0.0	13.8	45.1	225	59-68
CL152	L	0.0	13.8	45.4	185	62-69
CL163	L	0.0	13.2	44.7	223	63-68
CL172	L	0.0	14.0	45.7	195	64-70
CL271	M	0.0	13.6	45.4	238	60-70
Jazzman-2	L	--	--	--	--	--
Jupiter	M	0.0	13.9	47.1	286	62-71
LaKast	L	0.0	12.7	43.9	252	62-70
Mermentau	L	0.0	13.8	44.1	190	60-63
Roy J	L	0.0	12.7	42.5	240	62-70
RTCLXL729	L	0.0	12.7	41.8	230	59-69
RTCLXL745	L	0.0	13.1	41.0	231	59-70
RTXL753	L	0.0	12.7	42.4	267	52-68
Taggart	L	0.0	13.4	45.9	234	61-70
AREX1021	M	0.0	13.8	47.7	246	56-72
AREX1084	L	0.0	13.0	43.9	241	62-69
MEAN	--	0.0	13.4	44.6	230	60-69
LSD	--	0.0	0.8	0.8	26.8	--

[a] Grain length: L = long grain; M = medium grain.

Table 5. Results of Crittenden County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%)	------------	(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	20.7	45.2	195	67-69
Caffey	M	0.0	21.6	48.1	217	65-68
CL111	L	28.3	19.6	44.9	202	66-68
CL151	L	60.0	21.4	44.3	184	66-68
CL152	L	0.0	20.9	44.7	207	65-67
CL163	L	0.0	20.7	44.7	185	62-65
CL172	L	0.0	22.9	46.1	204	66-68
CL271	M	0.0	20.2	45.9	178	67-69
Jazzman-2	L	0.0	21.1	44.0	188	63-64
Jupiter	M	23.8	22.5	50.3	228	64-67
LaKast	L	24.5	18.6	44.6	205	65-69
Mermentau	L	0.0	21.4	45.3	197	66-68
Roy J	L	0.0	24.9	40.8	176	66-69
RTCLXL729	L	15.0	17.8	41.3	245	67-70
RTCLXL745	L	0.0	18.8	40.4	239	66-69
RTXL753	L	0.0	18.8	40.9	263	68-70
Taggart	L	0.0	21.9	46.7	210	66-69
AREX1021	M	2.5	20.1	48.9	241	68-70
AREX1084	L	0.0	22.2	44.2	195	66-69
MEAN	--	8.1	20.8	44.8	208	66-68
LSD	--	28.2	1.6	1.7	29.0	--

[a] Grain length: L = long grain; M = medium grain.

Table 6. Results of Greene County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	15.0	43.5	222	67-71
Caffey	M	0.0	14.8	45.9	250	65-70
CL111	L	0.0	13.4	42.6	221	61-69
CL151	L	0.0	14.4	43.2	242	65-70
CL152	L	0.0	13.7	43.0	222	64-70
CL163	L	0.0	13.8	43.5	234	62-69
CL172	L	0.0	14.4	44.8	240	66-70
CL271	M	0.0	14.6	44.0	232	66-71
Jazzman-2	L	0.0	15.3	41.3	211	64-68
Jupiter	M	0.0	15.3	46.7	272	65-69
LaKast	L	0.0	14.3	43.6	258	62-70
Mermentau	L	0.0	15.3	42.5	224	65-70
Roy J	L	0.0	16.1	41.2	230	63-69
RTCLXL729	L	0.0	12.9	41.4	213	66-71
RTCLXL745	L	0.0	12.5	40.4	220	59-70
RTXL753	L	0.0	13.0	41.4	280	59-71
Taggart	L	0.0	15.5	44.7	242	61-69
AREX1021	M	0.0	14.0	46.4	270	62-70
AREX1084	L	--	--	--	--	--
MEAN	--	0.0	14.3	43.3	238	63-70
LSD	--	0.0	1.2	1.4	26.9	--

[a] Grain length: L = long grain; M = medium grain.

Table 7. Results of Phillips County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%)	------------	(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	13.1	44.0	145	67-70
Caffey	M	0.0	15.6	46.1	182	67-72
CL111	L	0.0	12.9	43.5	169	64-68
CL151	L	0.0	13.6	43.3	173	63-66
CL152	L	0.0	13.7	42.3	160	60-63
CL163	L	0.0	14.1	43.0	143	62-65
CL172	L	0.0	14.7	44.0	160	65-68
CL271	M	0.0	13.8	43.4	140	60-68
Jazzman-2	L	0.0	13.9	43.1	128	61-63
Jupiter	M	0.0	16.2	46.2	183	63-70
LaKast	L	0.0	13.6	43.1	189	63-69
Mermentau	L	0.0	14.6	44.0	171	62-64
Roy J	L	0.0	14.4	41.7	169	61-67
RTCLXL729	L	0.0	13.3	40.6	209	67-72
RTCLXL745	L	0.0	12.9	40.2	217	63-70
RTXL753	L	0.0	13.1	41.3	223	61-69
Taggart	L	0.0	14.1	44.4	186	64-70
AREX1021	M	0.0	15.3	45.5	179	65-71
AREX1084	L	--	--	--	--	--
MEAN	--	0.0	14.0	43.3	174	63-68
LSD	--	0.0	1.1	1.3	15.9	--

[a] Grain length: L = long grain; M = medium grain.

Table 8. Results of Poinsett County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	20.2	47.3	215	71-74
Caffey	M	0.0	22.8	48.0	234	65-69
CL111	L	0.0	18.7	46.2	269	69-73
CL151	L	0.0	20.4	46.3	265	67-69
CL152	L	0.0	21.5	46.4	230	66-68
CL163	L	0.0	20.8	46.9	241	65-69
CL172	L	0.0	22.2	47.4	232	67-70
CL271	M	0.0	22.2	49.6	249	65-69
Jazzman-2	L	0.0	20.7	45.3	220	64-65
Jupiter	M	0.0	24.3	50.8	268	61-68
LaKast	L	0.0	19.7	46.4	253	65-72
Mermentau	L	0.0	22.0	46.5	225	66-68
Roy J	L	0.0	25.1	45.8	217	64-70
RTCLXL729	L	0.0	19.3	42.7	255	67-71
RTCLXL745	L	0.0	18.2	42.3	265	64-71
RTXL753	L	0.0	19.3	43.2	268	65-72
Taggart	L	0.0	23.2	48.0	247	63-70
AREX1021	M	0.0	21.4	50.8	281	68-70
AREX1084	L	--	--	--	--	--
MEAN	--	0.0	21.2	46.7	246	66-70
LSD	--	0.0	1.2	1.5	22.0	--

[a] Grain length: L = long grain; M = medium grain.

Table 9. Results of Prairie County Producer Rice Evaluation Program (PREP) Trial during 2014.

Cultivar	Grain length[a]	Lodging	Moisture	Test weight	Grain yield	Milling yield
		----------- (%) ------------		(lb/bu)	(bu/acre)	(HR-TR)
Antonio	L	0.0	14.6	44.5	189	65-71
Caffey	M	0.0	15.1	46.9	224	50-69
CL111	L	0.0	13.8	45.2	178	56-70
CL151	L	0.0	14.6	44.6	219	63-72
CL152	L	0.0	14.5	44.9	196	62-70
CL163	L	0.0	14.0	44.6	196	61-70
CL172	L	0.0	14.5	45.5	198	62-70
CL271	M	0.0	14.8	44.6	196	52-70
Jazzman-2	L	0.0	14.5	42.8	163	60-68
Jupiter	M	0.0	15.7	47.3	241	59-69
LaKast	L	0.0	14.1	45.9	212	56-70
Mermentau	L	0.0	14.8	44.6	199	65-70
Roy J	L	0.0	14.2	42.9	206	59-70
RTCLXL729	L	0.0	13.8	41.3	212	58-69
RTCLXL745	L	0.0	13.6	41.2	202	57-71
RTXL753	L	0.0	14.0	42.5	220	53-71
Taggart	L	0.0	15.4	46.1	219	56-70
AREX1021	M	0.0	14.8	48.0	225	48-70
AREX1084	L	--	--	--	--	--
MEAN	--	0.0	14.5	44.6	205.3	58-70
LSD	--	0.0	0.9	0.09	15.6	--

[a] Grain length: L = long grain; M = medium grain.

Table 10. Rice cultivar reactions[a] to diseases (2014).

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath spot
Antonio	S	S	--	MS	MS	S	S	MS	MS	--	--
Caffey	MS	MR	--	S	R	--	--	MS	--	--	--
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	--
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	--
CL151	S	VS	VS	VS	S	VS	S	S	MS	S	--
CL152	S	VS	S	S	MR	--	VS	S	--	--	--
CL163	MS	--	--	MS	--	--	--	--	--	--	--
CL172	MS	--	--	MS	--	--	--	S	--	--	--
CL271	S	MR	--	MS	MR	--	--	--	--	S	--
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S	--
Colorado	S	VS	--	S	MS	--	--	S	--	--	--
Della-2	S	R	--	S	MS	--	--	--	--	--	--
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	--
Jazzman	MS	S	S	S	S	S	MS	S	MS	MS	--
Jazzman-2	VS	S	--	VS	MR	--	S	S	--	--	--
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR	--
LaKast	S	S	MS	S	MS	S	S	S	MS	MS	S
Mermentau	S	S	VS	MS	MS	--	S	S	MS	--	--
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	--
RTCLXL729	MS	R	MS	MR	MS	S	MS	S	S	S	--
RTCLXL745	S	R	R	MR	MS	S	MS	S	S	S	--
RTCLXP756	MS	--	--	--	--	--	--	S	--	S	--
RTXL723	MS	R	S	MR	MS	S	MS	S	MS	S	--
RTXL753	MS	R	MS	MR	--	--	MS	S	--	S	--
RTXP754	MS	--	--	--	--	--	--	S	--	S	S
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS	--
Wells	S	S	S	S	S	VS	S	S	MS	MS	--

[a] Reaction: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; VS = Very Susceptible (cells with no values indicate no definitive Arkansas disease rating information is available at this time). Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development.

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist.

Validation of the Nitrogen Soil Test for Rice (N-STaR) on Clay Soils in Arkansas

J.T. Davidson, T.L. Roberts, C.E. Greub, A.M. Fulford, N.A. Slaton, J. Hardke, J. Shafer, S. Williamson, and C. Scott

ABSTRACT

The development of the Nitrogen Soil Test for Rice (N-STaR) allowed site-specific nitrogen (N) recommendations for rice on silt loam soils in Arkansas. Expansion of the site-specific N test into clay soils and its use in 27 counties in Arkansas necessitated the validation of N-STaR for rice produced on clay soil. In 2014, 6 sites across Arkansas were selected for their wide difference in native soil-N and planted to one of three rice cultivars. Stands were monitored for disease and pest pressure and yields were measured at the end of the season. Soil samples were taken at a 12-inch depth, analyzed using the N-STaR method, and the site-specific N rates were predicted using the calibration curves for 95% and 100% relative grain yield (RGY). In the validation trial, six treatments were compared; a control (0 lb N/acre); the N-STaR 95% and 100% RGY N-rates applied in a standard two-way split (2-WS) application with 45 lb N/acre applied at beginning internode elongation and the remainder preflood; the N-STaR 95% and 100% RGY N-rates applied in a single preflood (SPF) application; and the standard N recommendation based on soil texture and previous crop. Nitrogen rates predicted using N-STaR ranged from 50 lb N/acre to 210 lb N/acre. Rice yields obtained with the 95% RGY recommendation were statistically similar to the standard N-rate recommendation for all 6 sites and numerically greater at 2 of the 6 sites. For the 100% RGY recommendation, all 6 trials indicated similar yields could be achieved when compared to the standard N recommendation. This data indicates that N-STaR is able to predict site-specific N fertilizer rates for rice produced on clay soils over a wide range of environmental and production settings.

INTRODUCTION

Rice is a major crop in Arkansas, particularly around the Arkansas Grand Prairie and Mississippi Delta regions. In order to achieve optimum rice yields, N fertilization is required at 150 lb N/acre for most cultivars and is adjusted based on soil texture, rice cultivar, and the previous crop (Norman et al., 2013). While rice has one of the highest N-use efficiencies when managed correctly (Norman et al., 1992), fields with high levels of native N may not respond or respond very little to N fertilization leading to poor N use efficiency. The excess N fertilizer at these locations increases the likelihood of N losses into the environment, and is an unnecessary expense for rice producers. Since the development of the Illinois Soil Nitrogen Test (ISNT) by Mulvaney and Khan in 2001, interest has reawakened for a N soil test that measures potentially mineralizable N. The development of the N-STaR by Roberts et al. in 2011 enabled a site-specific N recommendation for rice producers in Arkansas rather than the standard approach based on cultivar, soil texture, and previous crop. Site-specific N recommendations take into account the native N of a soil and identify the sites where a decreased or increased rate of N, compared to the standard approach, is needed for optimal rice production. Soils separated by texture class—clays vs. silt loams and sands—yielded the strongest correlation between alkaline hydrolyzable-N and N rate required for optimum yield. In addition, Fulford et al. (2013) found the greatest predictability for clay soils to be a soil sample at the 0- to 12-inch depth. During the development of N-STaR for silt loam soils, the N-STaR calibration curves for the 95% and 100% relative grain yield (RGY) were validated to ensure predictability and to aid in the implementation of the N soil test (Roberts et al., 2013). Nitrogen Soil Test for Rice 95% and 100% calibration curves, similarly developed for clay soils, have not been validated in the field. The N-STaR method has the potential to decrease N loss into the environment and reduce the cost of fertilizer inputs for farmers (Williamson et al., 2014). The validation of N-STaR for clay soil will speed the adoption of this site-specific N soil test throughout Arkansas.

METHODS AND MATERIALS

In 2014, six field experiments were conducted across producer's fields (4 sites) and experiment stations (2 sites) in Arkansas. Clay soil locations were chosen to ensure a wide range of native soil-N availability across sites. The plots were 9 rows wide (7-inch spacing) and 15 ft in length, and arranged in a randomized complete block design. Rice was dry-seeded (100 lb seed/acre on station) and grown to the 3- to 5-lf stage before permanent flood was established (2- to 4-inch depth) and maintained until physiological maturity. Plots were monitored for pest pressure throughout the season. Four soil samples were taken at each location to a 12-inch depth, analyzed using N-STaR as outlined by Roberts et al. (2009), and the average N-STaR soil-test value was used to produce the 95% or 100% RGY N-rate recommendations for each location. Six treatments were conducted at each location; a control (0 lb N/acre); N-STaR 95% and 100% RGY applications applied in a 2-WS; N-STaR 95% and 100% RGY SPF applications; and the standard N recommendation. For the standard N recommendation and the N-STaR 95% and 100% RGY applications, a 2-WS of 45 lb N/acre applied midseason at panicle initiation and the remainder of the N recommendation was applied preflood at <5 days before permanent flood. The N-STaR SPF N recommendations were all applied preflood at <5 days before permanent flood. The N-STaR SPF applications were 20 lb N/acre less than the N-STaR 2-WS N recommendation calculated by the 95% and 100% RGY calibration curves. The N fertilizer applied was urea treated with the urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide; trade name Agrotain®, (Koch Agronomic Services, LLC, Wichita, Kan.). Grain was harvested from the middle four rows of each plot and weights were adjusted to 12% grain moisture and expressed in bushels (bu)/acre. Rough-rice grain yield was compared across treatments within a location using JMP Pro 11.0 (SAS Institute, Cary, N.C.) using a Fishers protected least significant difference test at the $P = 0.05$ level.

RESULTS AND DISCUSSION

The standard N recommendation currently used by Arkansas rice producers is altered according to cultivar, soil texture, and the previous crop (Norman et al., 2013). The introduction of N-STaR allowed producers to test for an index of potentially mineralizable N that was calibrated to a site-specific N recommendation. Two N-STaR calibration curves, the 95% RGY and the 100% RGY, were developed for use in clay soil that would provide site-specific N-rate recommendations needed to obtain the respective percentage (95% or 100%) of yield on a field by field basis. Historically, the 95% and 100% RGY fertilizer recommendations have not been significantly different with regard to yield, although the 100% RGY is often numerically higher. The substantially larger N-rate recommendation predicted by the 100% RGY reflects the high cost to the producer in achieving the last 5% of rice yield.

In order to reduce variability across locations, rough rice grain was compared at each site. The 2-WS N-STaR 100% RGY had no statistical difference from the standard N recommendation for all 6 of the sites, and the difference in yield ranged from -13 to 10 bu/acre from the standard N recommendation (Table 1). In contrast, the 2-WS N-STaR 100% RGY received a N rate that varied by -100 to 30 lb N/acre compared to the standard N recommendation. Similarly, the 2-WS N-STaR 95% RGY was not significantly different from the standard N recommendation for all 6 sites with a yield difference between -23 and 6 bu/acre and a N rate difference that varied between -125 to -30 lb N/acre when compared to the standard N recommendation. At two sites (P-4 and ES-2), rice receiving the 2-WS N-STaR 95% and/or 100% RGY N-fertilizer rates had numerically greater yield compared to the standard N recommendation while decreasing N fertilizer inputs. This phenomena may have occurred due to disease pressure or lodging in plots where excess N was applied. The findings suggest that the 95% and 100% RGY N-STaR calibration curves are accurately including the soil's ability to supply N in the ensuing recommendations.

Similar to the results of Roberts et al. (2013), the 2-WS N-STaR 95% and 100% RGYs were not significantly different from each other in the current study (Table 1). The

2-WS 95% RGY N-recommendation yielded a difference of -10 to 2 bu/acre with the difference in applied N being -30 to -60 lb N/acre when compared to the 2-WS 100% RGY N-recommendation. The verification of the 2-WS N-STaR 95% and 100% RGY fertilizer rate calibration curves will give producers the freedom to apply N fertilizer according to their individual management strategies.

Research has shown that N applied preflood can have very high N use efficiency (Wilson et al., 1989). Under optimum conditions, the SPF application translates into less N applied by the grower and lower application costs as the need for a midseason N application is removed. The SPF N-STaR application rates for clay soil were calculated using the 2-WS N-STaR 95% or 100% RGY N-rate calibration curves and subtracting from the preflood-N rate a constant 20 lb N/acre. For the SPF N-STaR 100% RGY recommendation, no sites were statistically different compared to the 2-WS N-STaR 100% RGY or the standard N-rate recommendations (Table 1). Differences in yield between the SPF N-STaR 100% RGY ranged from -7 to 9 bu/acre and -18 to 14 bu/acre compared to the 2-WS N-STaR 100% RGY and the standard N-rate recommendations, respectively. The reduction of 20 lb N/acre in a SPF application using the N-STaR 100% RGY N-recommendation appears to produce a similar yield compared to the N-STaR 100% RGY and standard N recommendation when the N fertilizer was applied in a 2-way split.

In contrast, the rice yield obtained with the SPF N-STaR 95% RGY application was not statistically different than the yield achieved with the 2-WS N-STaR 95% RGY application at 5 of the 6 sites (Table 1). For these 5 sites, the SPF N-STaR 95% RGY produced yields that differed between -19 to 9 bu/acre from the 2-WS N-STaR 95% RGY. At ES-2, there was a significant difference between the SPF N-STaR 95% RGY and the 2-WS N-STaR 95% RGY with the SPF application yielding 43 bu/acre less. Furthermore, when the SPF N-STaR 95% RGY was compared to the standard N recommendation, 3 of the 6 sites (P-2, ES-1, and ES-2) were significantly different. At P-2, ES-1, and ES-2, the SPF N-STaR 95% RGY recommendation produced lower yields (-42 to -26 bu/acre) than the standard N recommendation. The yields obtained with the SPF N-STaR 95% RGY and the standard N recommendation at the remaining 3 sites (P-1, P-3, and P-4) were not statistically different and varied from -24 to 10 bu/acre. However, 2 of the sites (P-3 and P-4) exhibited no statistical need for N fertilizer since there was no significant yield difference between the control (0 lb N/acre) and the standard N recommendation. This should be taken into consideration when evaluating the SPF N-STaR 95% RGY treatments. Overall, not enough SPF N-STaR 95% RGY sites had yields significantly different from the standard N recommendation to identify factors that may have contributed to the lower yields. From this preliminary research, it appears that the adjustment of a constant 20 units of N less for the SPF N-STaR 95% RGY compared to the 2-WS N-STaR 95% RGY recommendation may need to be altered. Perhaps a percentage rather than a constant amount of N decrease would be prudent because there are sites where the 95% RGY calibration curve recommends substantially less N than the standard N recommendation. Due to the preliminary nature of this study, additional research is advised in order to substantiate the results for the SPF N-STaR 95% and 100% RGY recommendations, and to identify and isolate the factors in the SPF N-STaR 95% RGY recommendation that contributed to the lower yields.

SIGNIFICANCE OF FINDINGS

The Nitrogen Soil Test for Rice (N-STaR) introduces a tool that provides an index of the potentially mineralizable N that may become available during the growing season. The growing concern with agronomic pollution along the Mississippi watershed and high N fertilizer prices will continue to promote the use of N-STaR in the state of Arkansas. The successful field validation of N-STaR for rice on clay soils ensures the soil test's predictability for rice N requirements and accelerates the adoption of N-STaR through on-field trials. In addition, the apparent success of the 20 lb N/acre decrease in the SPF N-STaR 100% RGY N-application allows for an additional fertilizer management tool that may decrease application costs and lower environmental impacts. On the other hand, the same constant reduction of 20 lb N/acre from the 2-WS N-STaR 95% RGY recommendation to make the SPF N-STaR 95% RGY N-recommendation needs further evaluation.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board. Appreciation is also expressed to the N-STaR lab personnel for conducting the analysis of N-STaR samples.

LITERATURE CITED

Fulford, A.M., T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson Jr., T.W. Walker, D.L. Frizzell, C.E. Greub, C.W. Rogers, S.M. Williamson, M.W. Duren, and J. Shafer. 2013. Evaluation of the Illinois Soil Nitrogen Test and the Nitrogen-Soil Test for Rice grown on clayey soils. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:204-212. Fayetteville, Ark.

Mulvaney, R.L. and S.A. Khan. 2001. Diffusion methods to determine different forms of nitrogen in soil hydrolysates. Soil Sci. Soc. Am. J. 65:1284-1292.

Norman, R.J., D. Guindo, B.R. Wells, and C.E. Wilson Jr. 1992. Seasonal accumulation and partitioning of nitrogen-15 in rice. Soil Sci. Soc. Am. J. 56:1521-1527.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. pp. 69-101. *In:* J.T. Hardke (ed.). Arkansas Rice production handbook. Misc. Publ. 192. University of Arkansas Cooperative Extension Service, Little Rock, Ark.

Roberts, T.L., R.J. Norman, N.A. Slaton, C.E. Wilson Jr., W.J. Ross, and J.T. Bushong. 2009. Direct steam distillation as an alternative to the Illinois soil nitrogen test. Soil Sci. Soc. Am. J. 73:1268-1275.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1-12.

Roberts, T.L., R.J. Norman, A.M. Fulford, and N.A. Slaton. 2013. Field validation of N-STaR for rice produced on silt loam soils in Arkansas. Soil Sci. Soc. Am. J. 77:539-545.

Williamson, S.M., T.L. Roberts, C.L. Scott, R.J. Norman, N.A. Slaton, A.M. Fulford, and C.E. Greub. 2014. Summary of the Nitrogen Soil Test for Rice (N-STaR) nitrogen recommendations in Arkansas during 2013. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:339-344. Fayetteville, Ark.

Wilson, C.E. Jr., R.J. Norman, and B.R. Wells. 1989. Seasonal uptake patterns of fertilizer nitrogen applied in split applications to rice. Sci. Soc. Am. J. 53:1884-1887.

Table 1. Comparison of the 2-way split (2-WS) N-STaR 95% and 100% relative grain yield (RGY), single preflood (SPF) N-STaR 95% and 100% RGY, and standard (Std. Rec.) fertilizer N-rate recommendations and the resulting rice grain yields for the four producer (P) and two experiment station (ES) sites utilized in 2014.

Fertilizer N-rate recommendation	P-1		P-2		P-3	
	N rate	Yield†	N rate	Yield†	N rate	Yield†
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
Check	0	130 bb	0	174 c	0	112 b
SPF 95% RGY	120	229 a	55	190 bc	50	137 a
2-WS 95% RGY	140	237 a	75	209 ab	70	128 ab
SPF 100% RGY	150	235 a	85	210 ab	80	135 ab
2-WS100% RGY	170	239 a	105	212 ab	100	126 ab
Std. rec.	200	253 a	200	216 a	200	137 ab

Fertilizer N-rate recommendation	P-4		ES-1		ES-2	
	N rate	Yield†	N rate	Yield†	N rate	Yield†
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
Check	0	145 a	0	38 c	0	41 c
SPF 95% RGY	55	161 a	100	91 b	130	114 b
2-WS 95% RGY	75	156 a	120	110 ab	150	157 a
SPF 100% RGY	85	165 a	130	123 a	150	150 a
2-WS 100% RGY	105	161 a	150	120 a	210	157 a
Std. rec.	200	151 a	180	133 a	180	151 a

† Means within a column followed by a different letter are significantly different at the $P = 0.05$ level.

Ammonia Volatilization and Rice Grain Yield as Affected by Simulated Rainfall Amount and Nitrogen Fertilizer Amendment

R.J. Dempsey, N.A. Slaton, T.L. Roberts,
R.J. Norman, R.E. DeLong, M.S. Fryer, and M.R. Parvej

ABSTRACT

Urea is the most common nitrogen (N) fertilizer source applied to rice (*Oryza sativa* L.) grown using the direct-seeded, delayed-flood method in Arkansas. Urea is susceptible to ammonia (NH_3) volatilization if not quickly incorporated into the soil by timely rainfall or flooding. A single experiment was conducted in 2014 on an alkaline Calhoun silt loam. Surface-applied urea (Urea) and N-(n-butyl) thiophosphoric triamide-amended urea (NBPT-Urea) were subjected to six simulated rainfall amounts ranging from 0 to 1 inch and the permanent flood was established 8 days after the application. Cumulative NH_3-N losses ranged from 0.03% to 1.4% for NBPT-Urea and 0.8% to 7.8% for Urea, with the greatest loss when no simulated rainfall was applied. Cumulative NH_3-N loss from NBPT-Urea was significantly lower than Urea when simulated rainfall was <0.90 inch, but similar when simulated rainfall amounts were ≥0.90 inch. Grain yield from rice fertilized with NBPT-Urea was greater than with Urea across all simulated rainfall amounts. Nitrification of hydrolyzed urea-N apparently occurs rapidly on this soil and denitrification represents a substantial N-loss pathway when the preflood urea is incorporated by a rainfall event several days before the flood can be established.

INTRODUCTION

Nitrogen is the nutrient applied in the greatest amount to rice grown using the direct-seeded, delayed-flood production method. Urea is the most commonly used N fertilizer due to its high N content (46%), low relative cost per unit of N, and ease of handling and application. Following urea application to the soil surface, urea reacts with the urease enzyme in the soil and undergoes hydrolysis. Hydrolysis of urea causes a pH increase in the soil adjacent to the fertilizer, which favors the formation of NH_3 and can accentuate N loss from surface-applied urea. Practices have been developed to reduce NH_3-N losses including application of urea to a dry soil surface at the 5-lf growth stage, use of an NBPT [N-(n-butyl) thiophosphoric triamide]-containing urease inhibitor, and flooding as quickly as possible (Norman et al., 2013). Prior research with direct-seeded, delayed-flood rice in Arkansas has reported losses from NH_3 volatilization ranging from 20% to 30% (Griggs et al., 2007).

Ten or more days are sometimes required to establish a flood in a field and incorporate the surface-applied urea, during which time rainfall events of various amounts may occur. Rainfall shortly after urea application has generally been considered helpful in reducing NH_3-N loss of urea-N since it incorporates the urea into the soil. A minimum of 0.6 inch of rainfall is needed to significantly reduce NH_3 volatilization from surface-applied urea (Holcomb et al., 2011). One often overlooked aspect of applying urea to a dry soil surface is that the dry soil not only delays urea hydrolysis, but it also slows the nitrification of NH_4-N to NO_3-N (Greaves and Carter, 1920). Although rainfall may effectively incorporate urea to prevent or significantly reduce NH_3-N loss, the potential for fertilizer-N loss via denitrification to gaseous N following nitrification of the urea-N between a rainfall event and flooding has not been examined. Our research objectives were to compare the effects of simulated rainfall amount and a urease inhibitor on NH_3 volatilization loss of preflood-applied urea and rice grain yield.

PROCEDURES

A single field experiment was conducted during the 2014 growing season at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) following soybean (*Glycine max* L. Merr.). Selected soil chemical properties for the study area are presented in Table 1. Phosphorus (60 lb P_2O_5/acre) and potassium (75 lb K_2O/acre) fertilizers were broadcast to each research area. The long-grain rice cultivar CL111 was drill-seeded into a stale seedbed at 90 lb seed/acre on 22 May 2014. Rice was drill-seeded into strips that included nine, 7.5-inch wide rows with a 12- to 16.5-inch plant-free alley around each plot.

Within each strip of rice, plots with dimensions of 6.0-ft wide by 7.5-ft long were flagged to establish individual plot boundaries for rainfall simulation and fertilization. The preflood-N treatments included untreated urea (Urea) and NBPT-treated urea (NBPT-Urea; Agrotain Ultra, 0.014 oz NBPT/lb urea; Koch Agronomic Services, LLC, Wichita, Kan.) at 105 lb N/acre. Nitrogen fertilizer was applied at 80% of the N rate predicted to produce maximum (100%) grain yield calculated from the Nitrogen Soil Test for Rice (N-STaR; Roberts et al., 2011). Prior to applying the N-fertilizer treatments, a 23.8-$in.^2$ aluminum ring, the same diameter as the NH_3 volatilization chambers, was placed into the ground and covered to identify the location of the chamber and exclude urea-N applied to the plot. After the N treatment was hand-applied to each plot, the chamber cover was removed, a pre-weighed N amount equivalent to 105 lb N/acre of the assigned N source was placed inside the aluminum ring, the simulated rainfall was applied, the ring was removed, and the chamber was installed. Simulated rainfall was applied using portable rainfall simulators as described in Dempsey et al. (2014). The water used for rainfall simulation was groundwater obtained from the station's spray pad water hose.

At the 4-lf stage, Urea and NBPT-Urea were applied to a dry soil surface at 7:00 PM on 16 June 2014. Nitrogen sources were subjected to simulated rainfall amounts of 0, 0.125, 0.25, 0.5, 0.75, or 1.0 inch and applied 15 to 19 h (e.g., start to finish) after the preflood urea-N was applied. A permanent flood was established 8 days after urea-N and simulated rainfall application.

Early-season NH_3 volatilization as affected by simulated rainfall amount and N source was evaluated using the semi-closed chamber method (Griggs et al., 2007; Massey et al., 2011). Measurement of NH_3 volatilization, temperature, and relative humidity were performed as described by Dempsey et al. (2014). Dry matter and total N uptake were measured by taking a 3-ft linear section of whole, above-ground rice plants at 5% to 10% heading, but will not be discussed in this article. At maturity, a 38-ft^2 section from the center 8 rows of each plot was harvested for grain yield using a small-plot combine. Immediately after harvest, grain weight and moisture were determined for each plot. The reported grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

The experiment was analyzed as a randomized complete block design with a 2 (N source) × 6 (rainfall amount) factorial structure and four replications of each treatment. Replicate NH_3 volatilization and grain yield data were regressed on simulated rainfall amount, allowing for linear and quadratic terms with coefficients depending on N source. The most complex nonsignificant ($P > 0.15$) model terms were removed sequentially and the model was refit until a satisfactory model was obtained. Comparisons between N sources were evaluated at $P = 0.10$ when necessary. Statistical analysis was performed using the Mixed procedure in SAS v. 9.3 (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Cumulative NH_3 volatilization for the 11 days between N application and flood establishment was influenced by a significant N source by rainfall interaction ($P < 0.0001$, Fig. 1). Cumulative NH_3 loss from both N sources decreased nonlinearly (quadratic) as simulated rainfall amount increased. After 11 days, the cumulative NH_3 loss ranged from 0.03% to 1.4% for NBPT-Urea and 0.8% to 7.8% for Urea with the greatest loss occurring from urea with no simulated rainfall. The NBPT-Urea prevented (e.g., not different than 0) NH_3 loss when simulated rainfall amounts were >0.6 inch. However, NH_3 loss from Urea was always greater than 0 across the range of simulated rainfall amounts. Cumulative NH_3 loss from NBPT-Urea was significantly lower than Urea when simulated rainfall was <0.9 inch, but similar when simulated rainfall amounts were ≥0.9 inch.

Rice grain yield was a negative, nonlinear (quadratic) function of simulated rainfall amount that consisted of a common quadratic term with linear and intercept terms dependent on N source (P = 0.0004, Fig. 2). The yields of rice fertilized with NBPT-Urea ranged from 146 to 164 bu/acre while rice yields receiving Urea ranged from 120 to 149 bu/acre. Grain yields from rice fertilized with NBPT-Urea were greater than Urea across all simulated rainfall amounts.

The use of NBPT significantly reduced NH_3 losses as measured in the semi-closed chambers and may have effectively delayed nitrification of urea-N prior to the establishment of the permanent flood. The grain yield response to simulated rainfall amount was the opposite of what would be predicted by the NH_3 volatilization loss from Urea as measured in the semi-closed chambers. Another N-loss pathway apparently played an important role in rice uptake of the preflood-N or, alternatively, N loss in the chamber was not representative of what happened in the field. The relative humidity (RH) within the chamber was constantly above the critical relative humidity (CRH) of urea, while outside the chamber, RH fluctuated above and below the CRH of urea suggesting that NH_3 loss in the chamber should be greater than what happened in the field. These results provide strong evidence that denitrification after flooding of the urea-derived NO_3-N occurs rapidly on this soil and represents a substantial N-loss pathway when the preflood urea is incorporated by rainfall several days before the flood can be established.

SIGNIFICANCE OF FINDINGS

Based solely on the measured NH_3 volatilization losses, rice grain yields were expected to increase as rainfall amount increased due to urea-N being incorporated into the soil. Yield results suggest that NH_3 volatilization and another N-loss pathway, which we assume is denitrification, may interact to influence cumulative N loss when rainfall occurs between urea application and the establishment of the permanent flood. Laboratory experiments have shown that nitrification of NH_4-N from urea-N fertilizer proceeds very rapidly (e.g., complete in 5 to 10 days) after application to the soil at the Pine Tree Research Station (Golden et al., 2009). The potential for NBPT to delay nitrification (e.g., via delayed urea hydrolysis), albeit by only a few days, may also reduce nitrification and subsequent N loss attributed to denitrification following flood establishment. Our results suggest that the most efficient uptake and use of urea-N occurs when urea is applied to a dry soil and no rainfall occurs before the field is flooded.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Check-off Program and the University of Arkansas System Division of Agriculture. We would like to thank the Pine Tree Research Station staff for their assistance with this study.

LITERATURE CITED

Dempsey, R.J., N.A. Slaton, T.L. Roberts, R.J. Norman, R.E. DeLong, and C.G. Massey. 2014. Rice grain yield as affected by simulated rainfall timing and nitrogen fertilizer amendment. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:247-252. Fayetteville, Ark.

Golden, B.R., N.A. Slaton, R.E. DeLong, R.J. Norman, and E.T. Maschmann. 2009. Nitrification inhibitors influence on rice grain yield and soil inorganic nitrogen fractions. *In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:215-223. Fayetteville, Ark.

Greaves, J.E. and E.G. Carter. 1920. Influence of moisture on the bacterial activities of the soil. Soil Sci. 10:361-387.

Griggs, B.R., R.J. Norman, C.E. Wilson Jr., and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake for conventional and conservation tilled dry-seeded, delayed-flood rice. Soil Sci. Soc. Am. J. 71:745-751.

Holcomb III, J.C., D.M. Sullivan, D.A. Horneck, and G.H. Clough. 2011. Effect of irrigation rate on ammonia volatilization. Soil Sci. Soc. Am. J. 75:2341-2347.

Massey, C.G., N.A. Slaton, R.J. Norman, E.E. Gbur, R.E. DeLong, and B.R. Golden. 2011. Bermudagrass forage yield and ammonia volatilization as affected by nitrogen fertilization. Soil Sci. Soc. Am. J. 75:638-648.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. pp. 69-101. *In:* J.T. Hardke (ed.). Arkansas Rice Production Handbook. Misc. Publ. 192. University of Arkansas Cooperative Extension Service, Little Rock, Ark.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1161-1171.

Table 1. Selected chemical property means (*n* = 2) of a Calhoun silt loam sampled (0- to 4-inch depth) prior to planting.

Soil	Mehlich-3 extractable nutrients								Total	Total
pH	P	K	Ca	Mg	S	Mn	Cu	Zn	C	N
(1:2)	(ppm)								(%)	
7.6	26	85	2040	330	10.6	339	1.2	1.6	1.08	0.09

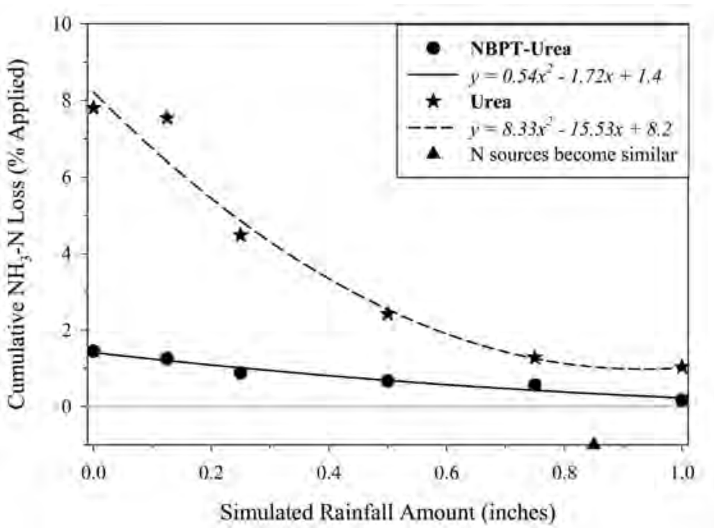


Fig. 1. Cumulative NH_3-N loss during the 11 days between N fertilizer application and flood establishment as influenced by the interaction of N source and simulated rainfall amount.

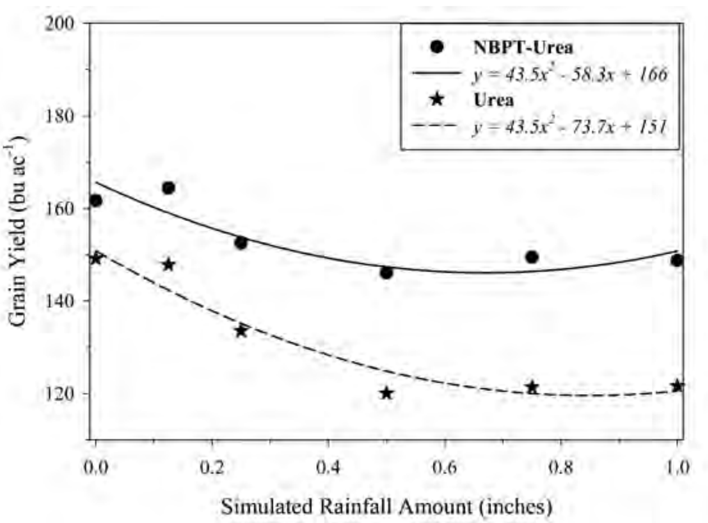


Fig. 2. Rice grain yield as influenced by the interaction of N source and simulated rainfall amount.

Rice Grain Yield as Affected by Simulated Rainfall Timing and Nitrogen Fertilizer Amendment

R.J. Dempsey, N.A. Slaton, T.L. Roberts,
R.J. Norman, R.E. DeLong, M.S. Fryer, and M.R. Parvej

ABSTRACT

Urea is recommended to be applied to a dry soil surface and incorporated quickly by flood establishment to reduce ammonia (NH_3) volatilization in the direct-seeded, delayed-flood method of rice (*Oryza sativa* L.) production. A single trial was conducted in 2014 on an alkaline Calhoun silt loam to evaluate rice grain yield as affected by five N sources [untreated urea (Urea), N-(n-butyl) thiophosphoric triamide (NBPT)-amended urea (UI-Urea), nitrapyrin-amended urea (NI-Urea), and NBPT+nitrapyrin-amended urea (UNI-Urea)] and three simulated rainfall timings [no simulated rainfall (NOSR), simulated rainfall applied before N application (SRBN), and simulated rainfall applied after N application (SRAN)]. Rice grain yield was influenced by the interaction of N source by simulated rainfall timing. Rice fertilized with the urease inhibitor (UI-Urea or UNI-Urea) produced greater rice yields compared to Urea or NI-Urea, regardless of simulated rainfall timing (SRBN and SRAN). Within an N source, rice receiving NOSR resulted in greater yields than SRBN and SRAN when Urea or NI-Urea were the N sources and similar yields when the N sources were UI-Urea or UNI-Urea.

INTRODUCTION

Urea is the nitrogen (N) fertilizer most commonly used to fertilize flood-irrigated rice because of its high N analysis (46% N), low cost relative to other N-containing fertilizers, and lack of NO_3-N. Despite these favorable characteristics, urea is also the granular N fertilizer that is most prone to NH_3 volatilization. Prior research with direct-seeded, delayed-flood rice in Arkansas has reported NH_3 volatilization losses ranging from 20% to 30% (Griggs et al., 2007). In order to minimize NH_3 loss, recommendations are to apply urea to a dry soil surface at the 4-to 5-lf stage, incorporate the urea-N into the soil and stop nitrification by establishment of a permanent flood as quickly as possible, and use of an N-(n-butyl) thiophosphoric triamide (NBPT) containing urease inhibitor (Norman et al., 2013). In some years, rainfall occurs frequently at the time rice is ready for N fertilization and prevents the application of urea to a dry soil surface. Ernst and Massey (1960) showed that 38% of urea-N was lost via NH_3 volatilization when applied to a soil with 20% (w/w) soil moisture, but loss decreased to 21% when applied to a soil with 10% (w/w) soil moisture.

After urea-N is applied, 10 days or more may be needed to establish the permanent flood. Rainfall before or after urea application can influence N loss via NH_3 volatilization before flood establishment and N loss caused by the nitrification/denitrification process whereby the urea-derived NH_4 is nitrified before flood establishment and then denitrified after flood establishment. Golden et al. (2009) showed that nitrification of urea-N was complete in as few as 10 days on an alkaline Calhoun silt loam incubated at 25 °C and a moisture content of 25% (w/w). The use of a nitrification inhibitor [i.e. Nitrapyrin (2-chloro-6-(trichloromethyl)-pyridine)] can be useful in slowing the rate of nitrification in flood-irrigated rice (Wells, 1977; Sharma and Prasad, 1980; Watanabe, 2006) and can possibly be a useful tool for reducing N-loss via denitrification. The potential for fertilizer-N loss via denitrification following nitrification of the urea-N between rainfall and flooding has not been examined. Our research objectives were to compare the effects of simulated rainfall timing and urease and nitrification inhibitor amendments applied to preflood urea-N on rice grain yield.

PROCEDURES

A single field experiment was conducted during the 2014 growing season at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) following soybean (*Glycine max* L. Merr.). Selected soil chemical properties for the study area are presented in Table 1. Phosphorus (60 lb P_2O_5/acre) and potassium (75 lb K_2O /acre) fertilizers were broadcast to the research area. The long-grain rice cultivar CL111 was drill-seeded into a conventionally tilled seedbed at 90 lb seed/acre on 22 May 2014. Rice was drill-seeded into strips that were comprised of nine 7.5-inch wide rows with a 12- to 16.5-inch plant-free alley around each plot.

Within each strip of rice, 6.0-ft wide × 7.5-ft long plots were flagged to establish individual plot boundaries for rainfall simulation and N fertilization. The preflood-N treatments included untreated urea (Urea), NBPT-treated urea (UI-Urea; Agrotain® Ultra, 0.014 oz NBPT/lb urea; Koch Agronomic Services, LLC, Wichita, Kan.), Nitrapyrin-treated urea (NI-Urea; Instinct, 1.26 lb nitrapyrin/acre; Dow Agrosciences, Indianapolis, Ind.), and NBPT+Nitrapyrin-treated urea (UNI-Urea) with each source applied at 105 lb N/acre. Nitrogen fertilizer was applied at 80% of the N rate predicted to produce maximum (100%) grain yield as determined by the Nitrogen Soil Test for Rice (N-STaR; Roberts et al., 2011).

Simulated rainfall was applied using portable rainfall simulators as described in Dempsey et al. (2014). The water used for rainfall simulation was groundwater obtained from the station's well. At the 4-lf stage, the N sources were applied between 7:00 and 8:00 PM on 16 June 2014. Simulated rainfall of 0.5 inch was applied to the designated plots 4 hours before N application and 18 hours after N application. Each N source was subjected to three simulated rainfall timings of: i) no simulated rainfall (NOSR), ii) simulated rainfall applied before N application (SRBN), and iii) simulated rainfall applied after N application (SRAN). The permanent flood was established 9 days after simulated rainfall and N application to allow time for NH_3 volatilization and nitrification to occur.

Total dry matter and total-N uptake were measured by taking a 3-ft linear section of whole, aboveground rice plants at 5% to 10% heading, but will not be discussed in this article. At maturity, a 38 ft^2 section from the center 8 rows of each plot was harvested for grain yield using a small-plot combine. Immediately after harvest, grain weight and moisture were determined for each plot. The reported grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

The experiment was a randomized complete block design with a 4 (N source) × 3 (simulated rainfall timing) factorial treatment structure and four blocks. Statistical analysis was performed using the MIXED procedure in SAS v. 9.3 (SAS Institute Inc., Cary, N.C.). Analysis of variance and mean separations were conducted using Fisher's protected least significant difference method (LSD) with differences interpreted at $P = 0.05$.

RESULTS AND DISCUSSION

Rice grain yield was influenced by the interaction of N source and simulated rainfall timing ($P = 0.0025$, Table 2). The greatest rice grain yields were produced by rice receiving UI-Urea and UNI-Urea, regardless of simulated rainfall timing (SRBN and SRAN), which yielded 9% to 38% greater than rice fertilized with Urea and NI-Urea. Rice receiving UNI-Urea, typically, produced intermediate yields suggesting that the urease and nitrification inhibitor mixture may influence one or both products' efficacy. Soares et al. (2012) reported that NH_3 volatilization loss was greater when NBPT was combined with the nitrification inhibitor dicyandiamide (DCD). They indicated that the efficacy of NBPT was not affected but the time and duration of NH_3 loss changed with the loss of NH_3 occurring after the NBPT lost its efficacy. Rice fertilized with Urea or NI-Urea typically produced similar yields across SRBN and SRAN timings. When there was NOSR, UI-Urea resulted in a rice yield greater than UNI-Urea and NI-Urea and similar to Urea. The Urea had a similar rice yield to UNI-Urea and greater than NI-Urea when there was NOSR. Rice with NOSR that received the UNI-Urea yielded a close to significant 10 bu/acre more than rice fertilized with NI-Urea and NOSR. When applied alone, the nitrification inhibitor appears to accentuate NH_3 volatilization loss from urea or may result in greater immobilization of fertilizer N. Previous research has reported no benefit to the use of the DCD nitrification inhibitor in reducing the nitrification rate of urea-N on the same Calhoun silt loam soil (Golden et al., 2009).

Across the three rainfall simulations within the Urea and NI-Urea N sources, the greatest grain yields were produced when rice received NOSR (Table 2). Within the

Urea-UI and Urea-UNI sources, grain yields were similar for each rainfall simulation (NOSR, SRAN, and SRBN). A dry soil surface represents the best condition to reduce N loss of urea-N. When urea-N is placed on a dry soil surface and there is no rainfall prior to establishing the permanent flood, N loss was apparently limited from both NH_3 volatilization and denitrification. However, when urea is added to a dry soil, followed by rainfall and there is an extended period of time to establish the flood then N loss is substantial.

SIGNIFICANCE OF FINDINGS

Under the conditions of this experiment, our results showed that applying urea-N to a dry soil surface and/or using an NBPT-containing urease inhibitor will help minimize N losses and maximize rice yield. Previous research reports that about 0.6 inch of rainfall is needed to effectively incorporate urea-N (Holcomb et al., 2011) on a fine sandy loam, but our experiment suggests that while adequate rainfall may limit NH_3 volatilization, the added moisture accelerates nitrification of urea-N and accentuates denitrification after the establishment of the flood. The NI-Urea treatment was not different than Urea within SRBN and SRAN simulated rainfall timings, indicating that the nitrification inhibitor did not slow the reaction of NH_4-N to NO_3-N or that NH_3 loss was greater. Urea treated with NBPT may have the potential of briefly delaying nitrification (e.g., via delaying urea hydrolysis), and therefore reducing the N loss attributed to denitrification. Growers should not treat urea with both NBPT and a nitrification inhibitor as our preliminary results and the literature suggest that N loss may increase.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Checkoff Program and the University of Arkansas System Division of Agriculture. We would like to thank the Pine Tree Research Station staff for their assistance with this study.

LITERATURE CITED

Dempsey, R.J., N.A. Slaton, T.L. Roberts, R.J. Norman, R.E. DeLong, and C.G. Massey. 2014. Ammonia volatilization and rice grain yield as affected by simulated rainfall amount and nitrogen fertilizer amendment. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:239-246. Fayetteville, Ark.

Ernst, J.W. and H.F. Massey. 1960. The effects of several factors on volatilization of ammonia formed from urea in the soil. Soil Sci. Soc. Am. J. 24:87-90.

Golden, B.R., N.A. Slaton, R.E. DeLong, R.J. Norman, and E.T. Maschmann. 2009. Nitrification inhibitors influence on rice grain yield and soil inorganic nitrogen fractions. *In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R.

Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series. 571:215-223. Fayetteville, Ark.

Griggs, B.R., R.J. Norman, C.E. Wilson Jr., and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake for conventional and conservation tilled dry-seeded, delayed-flood rice. Soil Sci. Soc. Am. J. 71:745-751.

Holcomb III, J.C., D.M. Sullivan, D.A. Horneck, and G.H. Clough. 2011. Effect of irrigation rate on ammonia volatilization. Soil Sci. Soc. Am. J. 75:2341-2347.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. pp. 69-101. *In:* Hardke, J.T. (ed.). Arkansas Rice Production Handbook. Misc. Publ. 192. University of Arkansas Cooperative Extension Service, Little Rock, Ark.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1161-1171.

Sharma, S.N. and R. Prasad. 1980. Effect of rates of nitrogen and relative efficiency of sulfur-coated urea and nitrapyrin-treated urea in dry matter production and nitrogen uptake by rice. Plant and Soil 55:389-396.

Soares, J.R., H. Cantarella, and M.L. de Campos Menegale. 2012. Ammonia volatilization losses from surface-applied urea with urease and nitrification inhibitors. Soil Biol. Biochem. 52:82-89.

Watanabe, T. 2006. Influence of 2-chloro-6-(trichloromethyl) pyridine and dicyandiamide on nitrous oxide emission under different soil conditions. Soil Sci. Plant Nutr. 52:226-232.

Wells, B.R. 1977. Nitrapyrin (2-chloro-6-(trichloromethyl)-pyridine) as a nitrification inhibitor for paddy rice. Down to Earth 32:28-32.

Table 1. Selected chemical property means (*n* = 2) of a Calhoun silt loam sampled (0- to 4-inch depth) prior to planting.

Soil	Mehlich-3 extractable nutrients								Total	Total
pH	P	K	Ca	Mg	S	Mn	Cu	Zn	C	N
(1:2)	(ppm)								(%)	
7.6	26	85	2040	330	10.6	339	1.2	1.6	1.08	0.09

Table 2. Effect of the nitrogen (N) source by simulated rainfall timing interaction on rice grain yield.

N source†	Simulated rainfall timing‡		
	SRBN	SRAN	NOSR
	------------------------ (bu/acre) ------------------------		
No N§	71		
UI-Urea	160 ab¶	151 abc	161 a
UNI-Urea	146 cd	147 cd	149 bcd
NI-Urea	120 g	126 fg	139 de
Urea	117 g	133 ef	151 abc
$LSD_{(0.05)}$	----------------------------11 ----------------------------		

† Abbreviations: UI-Urea, urea treated with urease inhibitor NBPT; NI-Urea, nitrapyrin-treated urea; Urea, urea alone; UNI-Urea, NBPT and nitrapyrin-treated urea.

‡ Abbreviations: SRBN, simulated rainfall before N application; SRAN, simulated rainfall after N application; NOSR, no simulated rainfall applied.

§ The no-N treatment was not used in the analysis of variance and is listed for reference.

¶ Means followed by same letter indicate no statistical difference at $P = 0.05$.

Planting Date Studies and Development of Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars, 2014

D.L. Frizzell, J.T. Hardke, E. Castaneda-Gonzalez, R.J. Norman, K.A.K. Moldenhauer, and X. Sha

ABSTRACT

The Degree-Day 50 (DD50) computer program has been one of the most successful programs developed by the University of Arkansas System Division of Agriculture. The program utilizes thermal units accumulated during the growing season to calculate predicted dates rice will reach growth stages critical for optimal crop management. However, the computer program must be continually updated as new conventional and hybrid rice cultivars are released. The DD50 thermal unit accumulations and grain yield performance of each new rice cultivar were evaluated over six seeding dates during 2014 in the dry-seeded, delayed-flood management system that is most commonly used in the southern United States. Rice cultivars evaluated in 2014 included: Antonio, Caffey, Clearfield (CL) 151, CL152, CL163, CL172, CL271, Colorado, Jupiter, LaKast, Mermentau, Roy J, Wells, the hybrids RiceTec CLXL729, RiceTec CLXL745, and RiceTec XL753, and the experimental line AREX1021. Grain and milling yields were measured at maturity to evaluate the influence of seeding date on grain and milling yield potential. The average number of days and DD50 thermal unit accumulations during vegetative growth ranged from 68 days and 1477 DD50s when seeded in late March to 48 days and 1323 DD50s when seeded in early June. The average number of days and DD50 thermal unit accumulations to reach 50% heading ranged from 98 days and 2278 DD50s when seeded in late March and 75 days and 2090 DD50s when seeded in mid June. Grain yield, averaged across cultivars, was highest when seeded 26 March and 18 April and lowest when seeded in June. When averaged across seeding dates, the cultivars had average head rice yields between 64% and 68%.

INTRODUCTION

The Degree-Day 50 (DD50) computer program was developed in 1975 by the University of Arkansas System Division of Agriculture for use as a crop management tool for rice. The program has been expanded over time to predict at least 26 key management decisions including nitrogen fertilizer timing, permanent flood establishment, timing of pesticide applications, reminders for disease scouting, and suggested harvest timing. Each DD50 file generated is field- and cultivar-specific for the current growing season. The program utilizes cultivar-specific data to predict rice plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. Thermal units are initially calculated from 30-year-average weather data which has been collected from the National Weather Service weather station closest to a rice producer's location in Arkansas. As the season progresses, the program is continually updated on a daily basis by replacing the 30-year average weather data values with actual in-season values.

The cultivar-specific data used to predict development are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Four to six seeding dates are utilized each year in these studies and are seeded within the recommended range of rice seeding dates for Arkansas. When a new rice cultivar is released, data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study were to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition to these objectives, the influence of seeding date on a cultivar's grain and milling yield performance was measured to determine optimal seeding dates for the new cultivars.

PROCEDURES

The study was conducted during 2014 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Fourteen varieties (Antonio, Caffey, CL151, CL152, CL163, CL172, CL271, Colorado, Jupiter, LaKast, Mermentau, Roy J, Wells, and AREX1021) were drill-seeded at a rate of 30 seed/ft^2 in plots 9 rows (7-inch spacing) wide and 15 ft in length. Three hybrids (RiceTec CLXL729, RiceTec CLXL745 and RiceTec XL753) were sown into the same plot configuration using the recommended reduced seeding rate for hybrids of 14 seed/ft^2. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates in 2014 were 26 March, 18 April, 2 May, 21 May, 5 June and 18 June. Normal cultural practices for dry-seeded, delayed-flood rice production were followed. All plots received 130 lb N/acre as a single preflood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied within 2 days of preflood-N fertilization and maintained until rice reached maturity. Data collected for each of the 6 seeding dates included maximum and minimum daily temperatures, date of seedling emergence, and the number of days and DD50 thermal units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) was also collected for the 26 March, 18 April, 21 May and 5 June seeding dates for selected cultivars. At maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushel/acre (bu/acre) basis. The dried rice was milled to obtain percent head rice and percent total white rice (HR-TR). Each seeding date was arranged in a randomized complete block design with four replications. Statistical analyses were conducted using PROC GLM v. 9.4 (SAS Institute, Inc., Cary, N.C.) and mean separation conducted based upon Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 7 to 20 days during 2014 (Table 1). Generally in seeding date studies, the days between seeding and emergence decreases as seeding date is delayed. In this study year, days from seeding to emergence decreased from 20 to 8 days as seeding date was delayed from late March until early May and then stayed relatively constant at 7 to 8 days from early May to the 18 June seeding date. Somewhat similarly, the time between seeding and flooding decreased from 63 days for the March seeding date to 33 days for the early June seeding date and then increased to 36 days for the mid-June seeding date. During 2014, time from emergence to flooding was 43 days for the March seeding date, 36 days for the April seeding date, and then decreased 2 to 6 days with each subsequent seeding date with the exception of the 18 June seeding date where it increased by 4 days.

The time required from emergence to 0.5-inch IE averaged 56 days across all cultivars sampled in the four seeding dates (Table 2). When averaged across cultivars, time to reach 0.5-inch IE ranged from 68 days when seeded in late March to 48 days when seeded in early June. The number of days required by each cultivar to reach 0.5-inch IE also decreased as seeding date was delayed from March to late May and then stayed relatively similar between the 21 May and 5 June seeding dates. During 2014, time of vegetative growth, averaged across seeding dates, ranged from 51 days for RT XL753 to 61 days for Jupiter. The DD50 thermal unit accumulations during vegetative growth ranged from a low of 1251 for RTXL753 to a high of 1511 for Jupiter when averaged across seeding dates.

The time required for plant development between emergence and 50% heading averaged 87 days across all cultivars and seeding dates during 2014 (Table 3). Average time for cultivars in each seeding date to reach 50% heading ranged from 98 days when seeded in late March to 75 days when seeded in early to mid-June. Average time for individual cultivars to reach 50% heading ranged from 79 days for RTCLXL745 and AREX1021 to 89 days for Roy J. Thermal unit accumulation between emergence and 50% heading averaged 2161 units during 2014. For individual cultivars, average DD50 thermal unit accumulation ranged from a low of 2040 for RTCLXL745 to a high of 2320 for Roy J, and was generally highest for all cultivars when seeded at the earliest seeding date of 26 March.

During 2014, average grain yield for the study was 186 bu/acre (Table 4). Grain yield, averaged across cultivars, was highest when seeded 26 March and 18 April and lowest when seeded in June. The average grain yield of the cultivars was similar when seeded in late March or mid-April, decreased as seeding date was delayed until May, remained similar for the two May seeding dates, and then decreased further as seeding date was delayed until June with the two June seeding dates yielding similarly. The hybrid RTXL753 maintained a fairly consistent grain yield across the March, April, and May seeding dates and then decreased significantly when seeded in June, but still averaged 221 bu/acre across all seeding dates. Other cultivars performing well averaged across seeding dates included the medium-grain experimental AREX1021, RTCLXL729, Jupiter, and LaKast.

During 2014, across seeding dates and cultivars, grain milling yield averaged 66% head rice and 70% total whie rice (Table 5). In general, both average percent head rice and average percent total white rice were lower in the 26 March and 21 May seeding dates and similar among the other four seeding dates. With very few exceptions, all cultivars averaged 60% or greater head rice yields during this study year regardless of seeding date. When averaged across seeding dates, the cultivars had average head rice yields from 64% to 68%.

SIGNIFICANCE OF FINDINGS

The data from 2014 will be used to refine the DD50 thermal unit thresholds for new cultivars and hybrids being grown. The grain and milling yield data will contribute to the database of information used by University of Arkansas System Division of Agriculture personnel to help producers make decisions regarding rice cultivar selection, particularly for early- and late-seeding situations.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board. Special thanks are also given to Mr. Emmett C. “Chuck” Pipkins for his dedication to making the DD50 Program possible.

Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 seeding date study in 2014 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding Date					
	26 March	18 April	2 May	21 May	5 June	18 June
Emergence date	15 April	28 April	10 May	29 May	13 June	25 June
Flood date	28 May	4 June	13 June	26 June	8 July	24 July
Days from seeding to emergence	20	10	8	8	8	7
Days from seeding to flooding	63	46	42	36	33	36
Days from emergence to flooding	43	36	34	28	25	29

Table 2. Influence of seeding date on Degree-Day 50 accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2014.

	Seeding Date									
	26 March		18 April		21 May		5 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Antonio	66	1419	56	1300	44	1215	44	1209	53	1286
CL163	68	1479	61	1457	54	1458	51	1392	59	1446
CL172	68	1472	60	1416	51	1373	49	1339	57	1400
CL271	72	1589	62	1492	54	1451	53	1456	60	1497
Colorado	65	1381	55	1278	44	1200	44	1209	52	1267
Jupiter	73	1616	64	1528	54	1444	53	1456	61	1511
LaKast	70	1537	60	1416	47	1300	48	1308	56	1390
Mermentau	64	1344	56	1323	44	1200	44	1201	52	1267
RT XL753	63	1330	54	1247	44	1201	45	1225	51	1251
Roy J	71	1567	61	1451	51	1390	51	1385	59	1448
Wells	69	1494	59	1401	51	1374	50	1357	57	1407
AREX1021	69	1494	58	1366	49	1348	49	1343	56	1388
Mean	68	1477	59	1390	49	1330	48	1323	56	1380
$LSD_{0.05}$	2.1	62.2	1.5	42.5	1.6	40.5	1.0	26.4	6.0	51.3

Table 3. Influence of seeding date on Degree-Day 50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2014.

	Seeding Date													
	26 March		18 April		2 May		21 May		5 June		18 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
Antonio	99	2302	89	2205	82	2128	79	2135	75	2081	74	2069	83	2153
Caffey	100	2337	92	2295	88	2280	79	2157	75	2089	74	2062	85	2203
CL151	98	2276	89	2213	82	2128	79	2157	75	2096	75	2082	83	2159
CL152	101	2350	91	2274	85	2201	80	2173	77	2140	79	2193	85	2222
CL163	97	2255	91	2258	85	2187	80	2181	76	2111	79	2186	84	2196
CL172	98	2281	90	2245	84	2159	79	2150	75	2104	76	2102	84	2173
CL271	99	2309	92	2301	88	2280	81	2196	78	2184	80	2212	86	2247
Colorado	94	2190	86	2128	81	2091	77	2095	72	1995	70	1958	80	2076
Jupiter	103	2432	91	2258	84	2173	80	2173	75	2104	74	2069	85	2201
LaKast	97	2252	88	2184	81	2093	78	2110	74	2074	74	2062	82	2129
Mermentau	98	2274	90	2221	82	2128	79	2150	75	2089	75	2095	83	2159
RT CLXL729	96	2218	86	2108	81	2093	79	2135	75	2089	75	2082	82	2121
RT CLXL745	92	2144	84	2062	78	2009	75	2044	71	1979	72	2002	79	2040
RT XL753	93	2165	86	2108	79	2048	76	2070	73	2042	71	1988	80	2070
Roy J	105	2475	95	2361	89	2324	83	2270	80	2233	83	2260	89	2320
Wells	99	2295	92	2287	84	2166	80	2181	76	2119	81	2222	85	2211
AREX1021	93	2168	85	2087	79	2054	75	2038	72	2003	72	2007	79	2059
Mean	98	2278	89	2211	83	2149	79	2142	75	2090	75	2097	87	2161
$LSD_{0.05}$	2.0	52.5	1.4	39.4	41.4	1.0	1.0	27.2	0.8	23.3	1.4	37.0	4.8	44.0

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2014.

	Grain yield by planting date						
Cultivar	26 March	18 April	2 May	21 May	5 June	18 June	Average
	----------	----------	----------	(bu/acre)	----------	----------	----------
Antonio	197	192	177	174	122	132	166
Caffey	249	231	157	207	132	147	187
CL151	225	232	191	181	140	151	186
CL152	220	209	174	173	139	143	176
CL163	216	206	173	171	107	138	168
CL172	235	213	183	182	137	141	182
CL271	218	219	153	174	136	136	173
Colorado	94	178	177	166	111	110	139
Jupiter	258	269	195	223	133	154	205
LaKast	242	255	203	199	131	147	196
Mermentau	194	210	185	173	139	136	173
RT CL XL729	244	242	213	211	166	187	210
RT CL XL745	207	229	207	190	160	160	192
RT XL753	221	253	240	240	189	180	221
Roy J	245	224	163	170	130	140	179
Wells	239	225	187	179	133	158	187
AREX1021	257	261	225	238	147	163	215
Mean	221	226	188	191	138	149	186
$LSD_{0.05}$	47.3	21.8	10.6	20.1	25.9	14.1	22.5

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2014.

	Milling yield by planting date						
Cultivar	26 March	18 April	2 May	21 May	5 June	18 June	Average
	(%HR - %TR[a])						
Antonio	67-72	70-73	70-73	66-69	67-70	70-72	68-71
Caffey	66-69	66-70	65-70	64-69	65-71	67-70	66-70
CL151	66-71	69-72	70-72	65-68	69-72	68-71	68-71
CL152	69-72	70-73	67-69	64-66	67-69	69-72	68-70
CL163	62-69	67-70	67-70	66-69	66-70	67-70	66-70
CL172	66-70	69-72	69-71	67-70	68-71	68-71	68-71
CL271	67-71	67-71	67-70	65-69	67-72	69-71	67-71
Colorado	55-64	65-71	65-70	63-68	66-70	67-71	64-69
Jupiter	64-68	63-68	64-68	61-67	64-69	65-69	64-68
LaKast	62-70	64-71	66-71	64-70	68-72	67-71	65-71
Mermentau	67-71	69-72	69-71	63-66	66-69	68-71	67-70
RT CL XL729	65-71	68-72	67-71	66-70	68-72	68-71	67-71
RT CL XL745	61-70	65-71	67-71	63-69	64-70	67-71	65-70
RT XL753	59-70	64-72	66-72	65-71	64-70	68-72	64-71
Roy J	59-71	64-72	66-72	64-71	64-70	67-72	64-71
Wells	64-71	68-72	69-72	67-72	69-73	68-72	68-72
AREX1021	66-71	68-71	67-70	65-69	69-72	67-71	67-71
Mean	64-70	67-71	67-71	65-69	67-71	68-71	66-70
$LSD_{0.05}$ % HR	2.9	0.9	1.8	2.5	1.9	1.2	1.4
$LSD_{0.05}$ % TR	1.5	0.5	2.0	2.6	1.7	0.9	0.9

[a] %HR - %TR = percent head rice - percent total rice.

Influence of Nitrogen Rate and Seeding Rate on Grain Yield of Roy J Rice Grown at Two Locations in Arkansas—First Year Results

D.L. Frizzell, J.T. Hardke, E. Castaneda-Gonzalez, R.J. Norman, and M.W. Duren

ABSTRACT

Seeding rate recommendations for rice grown in Arkansas are based on achieving an optimum stand density of 10 to 20 plants/ft^2 for conventional varieties. The current recommendation of 30 seed/ft^2 is a baseline and actual seeding rate is adjusted based on considerations such as planting date, seedbed preparation, soil type, seeding method, or pest pressure. For various reasons, primarily due to environmental conditions, the recommended seeding rate for a given planting situation at times does not result in an optimum stand density. In these situations, often a recommendation is made to increase nitrogen (N) rates with the goal of increasing tillering in the plants. Previous studies using older cultivars have shown grain yield could be increased in thin stands by increasing the amount of fertilizer N applied preflood, but it is unclear if the findings from those studies can still be applied to newer, more vigorous cultivars grown today. Therefore, the objective of this study was to examine the relationship between rice seeding rates and N application rates of a currently grown cultivar. A study was initiated during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay soil and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil using the conventional rice variety Roy J. Four treatments were utilized at each location that consisted of combinations of two seeding rates (44 or 88 lb seed/acre) and two preflood-N rates (90 or 150 lb N/acre). At NEREC, the higher preflood-N rate resulted in greater grain yields regardless of seeding rate. At RREC, the lowest grain yield was observed with the 44 lb/acre seeding rate and 90 lb/acre of preflood-N rate combination, but grain yield increased as either seeding rate

or N rate was increased with the highest grain yield observed when 150 lb N/acre was applied to rice seeded with 88 lb seed/acre. This initial dataset indicates an increase in preflood-N rate applied to rice seeded at a lower than optimum seeding rate may have a positive effect on grain yield of newer cultivars.

INTRODUCTION

Seeding rate recommendations for rice grown in Arkansas are based on achieving an optimum stand density of 10 to 20 plants/ft^2 for conventional varieties and 6 to 10 plants/ft^2 for hybrids (Wilson et al., 2013). The current recommendation for conventional varieties of 30 seed /ft^2 is a baseline and actual seeding rate is adjusted based on considerations such as planting date, seedbed preparation, soil type, seeding method, or pest pressure. For various reasons, primarily due to environmental conditions, the recommended seeding rate for a given planting situation at times does not result in an optimum stand density. In these situations, often a recommendation is made to increase N rates with the goal of increasing tillering in the plants. This recommendation for additional N is based on previous studies that have shown grain yield could be increased in thin stands by increasing the amount of fertilizer N applied (Counce and Wells, 1990; Counce et al., 1992; Wells and Faw, 1978).

Work done by Wells and Faw (1978) using Starbonnet rice seeded on a DeWitt silt loam at rates of 60, 120, and 270 lb seed/acre and preflood-N rates of 60, 120 and 180 lb N/acre determined that both N rate and seeding rate influenced grain yield each year of the study. During 1972, grain yield increased with each increase in N rate at the 60 lb/acre seeding rate, but only increased at the 120 lb/acre seeding rate when N rate was increased up to 120 lb N/acre. Grain yield declined with an increase in preflood N from 120 to 180 lb N/acre. During 1973, grain yield was maximized with the combination of 120 lb N/acre applied to either the 60 or 120 lb/acre seeding rate.

Counce and Wells (1990) noted a significant interaction between initial plant population density and preflood-N rates for Lemont and Newbonnet on a Sharkey clay soil across the two-year study. Grain yield increased with each increase in N rate at the lowest seeding rate of 5 seed/ft^2 and increased at the 40 or 125 seed/ft^2 seeding rate with N rates up to 70 lb N/acre. Grain yield at each of those seeding rates remained somewhat similar when N rate increased from 70 to 100 lb N/acre. Results from the yield component portion of the study showed that at the lowest seeding rate, grain yield increase with each subsequent increase in N rate was mainly due to additional tillering. As seeding rate increased to 40 or 125 seed/ft, increased grain yield was due to increased number of grains per panicle. Results from a study conducted by Counce et al. (1992) at the same location using Lemont rice seeded at 5, 25, and 45 seed/ft^2 were in agreement with the earlier study in that both years showed a greater preflood-N requirement for the two lower seeding rates than for the near optimum seeding rate of 45 seed/ft^2. The optimum seeding rate for rice varieties at that time was considered to be somewhere around 40 seed/ft^2.

In contrast, a study conducted at several locations in Louisiana, Mississippi, and Missouri using newer varieties Cheniere and Wells seeded at 15, 30, and 60 seed/ft^2, and preflood-N rates of 60, 120, and 180 lb N/acre, found grain yield is influenced by seeding rate and also by N rate but there was no interaction between N rate and seeding rate (Bond et al., 2008). Similar results were observed in a study using Cheniere and Jupiter seeded into a Crowley silt loam at rates of 15, 30, 45, and 60 seed/ft^2 (Harrell and Blanche, 2010). Nitrogen rates of 90, 120, 150, and 180 lb N/acre were applied preflood as urea. The was no interaction of N rate and seeding rate for either Cheniere or Jupiter, only the main effect of N rate or seeding rate influenced grain yield of the two cultivars.

On-going work is conducted each year to evaluate the effect of N rate or seeding rate on rice grain yield in Arkansas, but there has been no known work done within the University of Arkansas looking at the combined effect of N rate and seeding rate on grain yield. Recent work conducted in surrounding states regarding the effect these two parameters have on grain yield has been in contrast to findings of previous studies. It is unclear if the data obtained from work with older cultivars can still be applied to newer, more vigorous cultivars grown today. Therefore, the objective of this study was to examine the relationship between rice seeding rates and nitrogen (N) application rates of a currently grown cultivar.

PROCEDURES

A study was initiated during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay soil and at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Four treatments were utilized at each location that consisted of combinations of two seeding rates (44 or 88 lb seed/acre) and two preflood-N rates (90 or 150 lb N/acre). The treatments were arranged in a randomized complete block design with three replications. The conventional rice cultivar, Roy J, was drill-seeded into a conventionally tilled seedbed on 7 May at NEREC and 12 May at RREC in plots 9 rows (7-inch spacing) wide and 15 ft in length. Seed was treated with CruiserMaxx Rice seed treatment to reduce impact of early-season insects and seedling disease. All N treatments were applied as urea onto a dry soil surface at the 4- to 5-lf growth stage. The permanent flood was established within 2 days of N application and maintained until rice reached maturity. At maturity, the center five rows of each plot were harvested and the moisture content and test weight of the grain were determined. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. A bushel of rice weighs 45 pounds (lb). Statistical analyses were conducted using PROC GLM SAS v.9.4 (SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's protected least significant difference test (P = 0.10) where appropriate.

RESULTS AND DISCUSSION

During 2014 at NEREC, the higher preflood-N rate of 150 lb N/acre resulted in greater grain yields regardless of seeding rate (Fig. 1). At RREC, the lowest grain yield was observed with the 44 lb/acre seeding rate and 90 lb N/acre preflood-N rate, but increased as either seeding rate or N rate was increased and reached a maximum of 161 bushels when 150 lb N/A was applied to plots seeded with 88 lb seed/acre.

Treatment effects were also noted for other parameters at the two locations during 2014. At NEREC, lodging was greater when 150 lb N/acre was applied preflood to both seeding rates (Fig. 2). Lodging was minimal when 90 lb N/acre was applied to the 44 lb/acre seeding rate. Lodging was not at factor at RREC during 2014.

Treatment combinations did not have an effect on harvest moisture at NEREC likely due to the low overall moisture of the trial, but harvest moisture was higher at RREC with the higher preflood-N rate (Fig. 3). Maturity of rice is delayed as the N rate increases, therefore higher harvest moisture would be expected for the rice receiving the higher preflood-N rate.

Test weight (lb/bu) of grain harvested at NEREC was similar between the two preflood-N rates within the 44 and 88 lb/acre seeding rates (Fig. 4). The treatment combination of the 44 lb seed/acre rate fertilized with 90 lb N/acre resulted in greater test weight than either treatment seeded at 88 lb seed/acre. The test weight of the 44 lb seed/acre rate fertilized with 150 lb N/acre was similar to the 88 lb seed/acre rate fertilized at both preflood-N rates. Although numerical test weight differences are evident at the RREC during 2014, the variability of the test weight data did not enable treatment differences to be significant.

SIGNIFICANCE OF FINDINGS

This initial dataset indicates an increase in preflood-N rate applied to rice seeded at a lower than optimum seeding rate may have a positive effect on grain yield of newer cultivars. The study will be continued in 2015 and will include evaluating the effect these treatment combinations may have on milling yield in addition to the current parameters of grain yield, harvest moisture, test weight, and lodging. Stand density will be measured to identify low plant populations. .

ACKNOWLEDGMENTS

This and other studies are supported through grower check-off funds administered by the Arkansas Rice Research and Promotion Board. We wish to thank the following people for their dedication to making these possible each year: Bethany Berger, Shawn Clark, and Chuck Pipkins.

LITERATURE CITED

Bond, J.A., T.W. Walker, B.V. Ottis, and D.L. Harrell. 2008. Rice seeding and nitrogen rate effects on yield and yield components of two rice cultivars. Agron. J. 100:393-397.

Counce, P.A. and B.R. Wells. 1990. Rice plant population density effect on early-season nitrogen requirement. J. Prod. Agric. 3:390-393.
Counce, P.A., B.R. Wells, and K.A. Gravois. 1992. Yield and harvest index responses to preflood nitrogen fertilization at low rice plant populations. J. Prod. Agric. 5:492-497.
Harrell, D.L. and S.B. Blanche. 2010. Tillage, seeding, and nitrogen rate effects on rice density, yield and yield components of two rice cultivars. Agron. J. 102:592-597.
Wells, B.R. and W.F. Faw. 1978. Short-statured rice response to seeding and N rates. Agron. J. 70:477-480.
Wilson, C.E. Jr., Y. Wamishe, G. Lorenz, and J. Hardke. 2013. Rice stand establishment. pp. 31-40. *In:* J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service, Misc. Publ. 192. Little Rock, Ark.

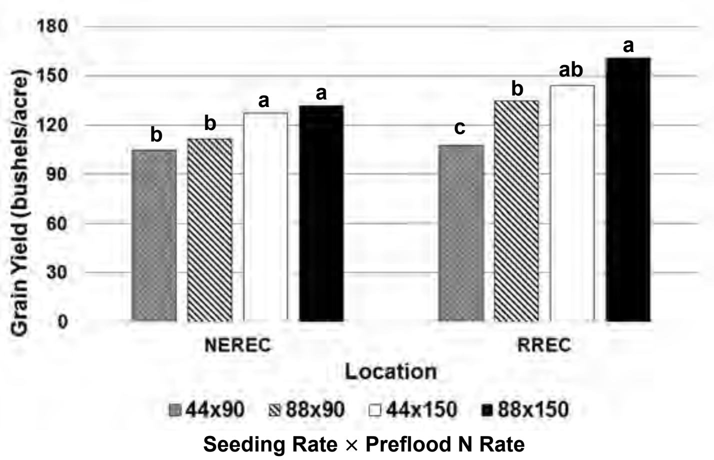


Fig. 1. Influence of seeding rate and nitrogen (N) rate on grain yield of Roy J during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC). Means within a location with similar letters are not significantly different (*P* < 0.10).

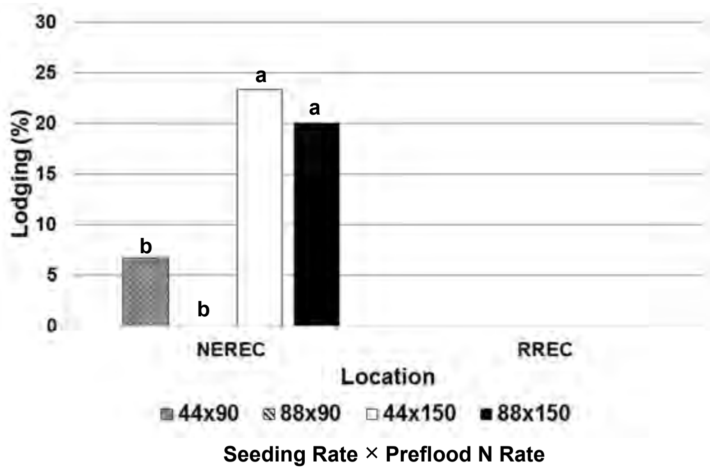


Fig. 2. Influence of seeding rate and nitrogen (N) rate on lodging of Roy J during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC). Means within a location with similar letters are not significantly different (*P* < 0.10).

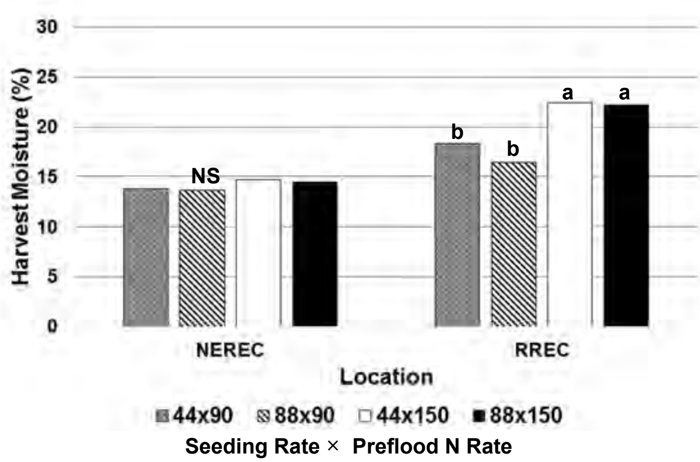


Fig. 3. Influence of seeding rate and nitrogen (N) rate on harvest moisture of Roy J during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC). Means within a location with similar letters are not significantly different (*P* < 0.10). NS indicates not significant.

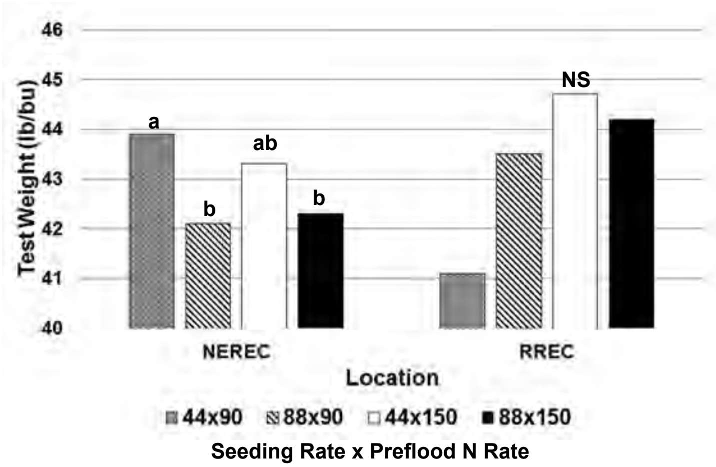


Fig. 4. Influence of seeding rate and nitrogen (N) rate on test weight of Roy J during 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC). Means within a location with similar letters are not significantly different (*P* < 0.10). NS indicates not significant.

Validation of Soil-Test-Based Fertilizer Recommendations for Rice

M. Fryer, N.A. Slaton, T.L. Roberts, J. Hardke. R.E. DeLong,
R. Dempsey, M.R. Parvej, J. Hedge, and S. Hayes

ABSTRACT

Farmers rely on accurate fertilizer recommendations, but crop yield responses to fertilization do not always agree with soil-test report interpretations. The objective of our research was to validate the accuracy of existing soil-test-based fertilizer recommendations in predicting rice (*Oryza sativa* L.) yield responses to phosphorus (P) and potassium (K) fertilization. Ten trials were established at four different University of Arkansas System Division of Agriculture experiment station fields in 2014. Three comparisons evaluated at three levels of significance (0.05, 0.10, and 0.25) were used to validate the fertilizer recommendations: 1) P fertilizer alone compared to no fertilizer, 2) K fertilizer alone compared to no fertilizer, and 3) treatments that received both P and K fertilizer compared to no fertilizer. Results showed soil-test interpretations for P and K were 67% and 64% accurate, respectively, in predicting the correct crop yield response, but the level of significance affected accuracy. The majority of the error occurred with sites testing ≤25 ppm P and ≤90 ppm K suggesting soil-test level definitions may need to be changed to improve accuracy.

INTRODUCTION

Technological improvements are constantly advancing and changing the way tasks are completed, especially in agriculture. Precision agriculture technologies, in particular variable-rate fertilization (VRF), are regularly used and are being increasingly adopted in production agriculture (Holland et al., 2013). These technological advancements may be outpacing the science behind them. Soil tests are used to determine soil-P and -K availability for crop nutrient management. Since the early 1900s, soil testing has played a crucial role in improving crop yields (Stewart et al., 2005). Research showing the relationship of crop yield and soil-test nutrient availability has been performed, but an often overlooked area of research is measuring how accurate the soil-test results are in predicting the correct crop yield response to fertilization. The utility of VRF technology is only as good as the accuracy of the soil test used to make the fertilizer recommendation. The goal of the research was to quantify and improve the accuracy of soil-test-based P and K fertilizer recommendations for flood-irrigated rice.

PROCEDURES

Ten P and K fertilization trials were established in University of Arkansas System Division of Agriculture experiment station fields (i.e., Northeast Research and Extension Center, NEREC; Pine Tree Research Station, PTRS; Rice Research and Extension Center, RREC; and Rohwer Research Station, RRS) during 2014. Soil and agronomic information as well as the field name that will be used in this report are listed in Table 1. Preliminary soil samples were taken in early spring to define fertilizer treatments at each site. Plots ranged from 5.3- to 5.6-ft wide × 16- to 20-ft long. Once plot boundaries were established, 0- to 4-inch deep samples were taken from each replicate (n = 6). Plant-available, soil nutrients were extracted using the Mehlich-3 solution and determined analytically by inductively coupled plasma spectroscopy. Selected soil chemical property means are listed in Table 2.

Crop management practices for each trial closely followed recommendations from the University of Arkansas System Division of Agriculture Cooperative Extension Service. Urea was applied at the 5-lf stage and the rice was flooded at all sites except PTRS-F18 and PTRS-F5 where N fertilization and flooding was delayed due to wet-soil conditions. Ammonium sulfate (150 lb/acre) was applied at PTRS-F18 and PTRS-F5 to supplement N needs until field conditions were conducive for preflood urea application. The N-STaR-predicted, preflood-N rates of urea ranged from 100 to 180 lb N/acre. A midseason urea application (45 lb N/acre) was applied at RRS-Loam, RRS-Clay, NEREC-S4, NEREC-S14, RREC-E, and RREC-W.

Each trial contained a total of six treatments having four K_2O rates and two P_2O_5 (0 and 60 lb P_2O_5/acre) rates including 1) the recommended P rate plus 0 lb K_2O/acre, 2) the recommended P rate plus 60 lb K_2O/acre, 3) the recommended P rate plus 90 lb K_2O/acre, 4) the recommended P rate plus 120 lb K_2O/acre, 5) the recommended K rate plus the second P_2O_5 rate, and 6) no P and K fertilizer (control). Selected sites received foliar-applied zinc (1 lb Zn/acre) to ensure that Zn deficiency was not growth and yield limiting.

Plant samples were taken in selected plots at the midtillering and early heading stages to evaluate tissue P and K concentrations. Seed was also saved from each plot, weighed, and digested, but neither the tissue nor seed data will be presented in this report. Five to 8 of the 9 rows in each plot of rice were harvested with a small plot combine, weights and moistures were recorded, and grain yields calculated and expressed in bushels (bu)/acre adjusted to 12% grain moisture.

The six treatments in each trial were arranged as a randomized complete block design with six blocks analyzed using the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). Three single-degree-of-freedom contrasts were used to compare grain yields: P fertilizer alone compared to no fertilizer, K fertilizer alone compared to no fertilizer, and P and K fertilizer compared to no fertilizer. Three levels of significance ($P \leq 0.05$, $P \leq 0.10$, and $P \leq 0.25$) were used to define yield differences. Responses to fertilization are labeled as a yield increase, no change, or decrease. The hypothesis test was that soils with Very Low to Low nutrient levels would show a yield increase to fertilizer, and soils with Optimum and Above Optimum nutrient levels would show no change in yield. For sites with Medium soil-test nutrient levels, no change or a small yield increase to fertilization would be considered correct. A yield decrease is not expected from fertilization with the fertilizer rates used in the study, but is included as a possible outcome.

RESULTS AND DISCUSSION

There were three clayey and seven loamy sites in the fertilization studies (Table 2). Positive yield increases to either P and/or K fertilizer were expected at the seven loamy sites. Table 3 summarizes the yield responses to P, K, and P and K fertilization. All three clayey sites (RRS-Clay and NEREC-S4 and NEREC-S14) were not expected to show yield increases to P or K fertilization, but a 10 bu/acre yield increase was measured at NEREC-S4 when K was applied. Harvest notes for NEREC-S4 showed that lodging numerically decreased from 60% to 67% for rice receiving no K to 55% to 33% as K rate increased indicating lodging may have resulted in poor harvest efficiency and resulted in the yield difference. Soil-test P and K at the two remaining clayey sites accurately predicted that yields would not respond to P or K fertilization.

For the seven loamy sites, soils tested in the Very Low (2 sites), Low (1), Medium (3), and Above Optimum (1) P levels, and Very Low (1), Low (4), and Medium (2) K levels (Tables 2 and 3). Regardless of soil-test level, rice at none of the sites responded positively to P-only fertilization (Table 3). The PTRS-I10 was the only site with both suboptimal P and K levels that responded positively (+9 bu/acre) to the K-only treatment as well as the treatment that received both P and K (+7 bu/acre).

The level of significance at which the results were evaluated affected the accuracy of the interpretations for K (Table 4). The most frequently occurring error for both soil-test P and K predictions was the soil test predicted that a yield increase to fertilization would occur (≤25 ppm P and ≤90 ppm K), but no increase was measured.

SIGNIFICANCE OF FINDINGS

Fertilizer recommendations were 67% accurate in predicting rice yield response to P fertilization, regardless of the significance level (Table 4). The accuracy of soil-test K interpretation increased from 56% to 62% when the response to fertilization was evaluated at $P \leq 0.25$. Most of the prediction errors occurred in the suboptimal soil-test category when a yield response was expected but no response was measured. Results from this research indicate that the soil-test P and K concentrations used to define each soil-test level need to be refined to account for the error that occurred in the yield predictions or an improved and more accurate soil-test method is needed. Other aspects of this research that were not presented in this report, such as horizontal, vertical, and temporal variability, may help explain some of the error that occurred.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board through grower check-off funds and is greatly appreciated.

LITERATURE CITED

Stewart, W.M., D.W. Dibb, A.E. Johnston, and T.J. Smyth. 2005. The contribution of commercial fertilizer nutrients to food production. Agron. J. 97:1-6.

Holland, J.K., B. Erickson, and D. Widmar. 2013. Precision agriculture services dealership survey results. CropLife. Purdue University. (accessed 11 Dec. 2014). Available at: http://agribusiness.purdue.edu/resources/2013-precision-agricultural-services-dealership-survey-results

Table 1. Selected soil and agronomic information.

Site[a]	Soil series	Variety	Row width	Planting date	Previous crop and fertilizer[b]		
					Crop	P_2O_5	K_2O
			(in.)			---- (lb/acre) ----	
NEREC-S14	Sharkey clay	Roy J	7.0	6 May	Soybean	0	0
NEREC-S4	Sharkey clay	Roy J	7.0	6 May	Fallow	0	0
PTRS-F18	Calhoun	Roy J	7.5	19 April	Soybean	40	60
PTRS-F5	Calhoun	Roy J	7.5	18 April	Soybean	0	0
PTRS-I10	Calloway	Roy J	7.5	24 April	Soybean	0	0
PTRS-MJC	Calhoun	CL111	7.5	22 May	Fallow	0	0
RREC-E	Dewitt	CL152	7.0	12 May	Soybean	0	0
RREC-W	Dewitt	CL152	7.0	12 May	Soybean	0	0
RRS-Clay	Sharkey/Desha	CL152	7.0	7 May	Rice	0	0
RRS-Loam	Desha	CL152	7.0	7 May	Soybean	0	0

[a] Abbreviations include: NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name

[b] Crop grown and fertilizer applied during the 2014 growing season.

Table 2. Selected soil chemical property means (n = 6) from the unfertilized control in P and K fertilization trials conducted at multiple sites during 2014.

	4 inch sample[b]								12 or 18 inch sample[b]		
Site[a]	pH	P	K	Ca	Mg	S	Zn	SOM	pH	P	K
		(ppm)						(%)		(ppm)	
NEREC-S14[12]	7.0	47 (2)	286 (19)	4300	1022	7	4.5	4.2	7.1	35 (3)	300 (26)
NEREC-S4[12]	7.8	69 (3)	271 (17)	4885	1038	14	3.9	3.6	7.5	54 (4)	308 (23)
PTRS-F18[18]	7.8	13 (3)	55 (16)	2264	360	11	1.6	2.3	6.8	10 (5)	58 (10)
PTRS-F5[18]	7.2	30 (4)	88 (12)	1673	325	7	2.5	2.6	6.9	14 (3)	57 (7)
PTRS-I10[18]	6.6	27 (1)	72 (7)	1425	304	9	1.9	2.4	5.3	10 (3)	53 (5)
PTRS-MJC[18]	7.6	61 (5)	90 (8)	2241	398	19	2.7	2.4	5.9	19 (2)	60 (4)
RREC-E[18]	7.1	34 (8)	109 (18)	1805	146	6	1.2	2.0	6.2	9 (3)	66 (11)
RREC-W[18]	7.0	13 (4)	85 (8)	1623	205	7	1.5	1.9	5.5	5 (0)	88 (15)
RRS-Clay[12]	7.8	54 (2)	192 (12)	4476	826	28	2.7	3.1	7.5	57 (3)	199 (15)
RRS-Loam[18]	7.2	16 (4)	126 (8)	1886	656	6	1.3	2.0	5.9	13 (7)	130 (17)

[a] Abbreviations include: NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name and the superscripted value indicates the depth of the second set of soil samples presented in the three right-hand columns that were taken in addition to the 0- to 4-inch depth.

[b] The value in parentheses () is the standard deviation of the mean soil-test P or K value.

Table 3. Expected rice yield response to P, K, or P and K fertilization compared to a no P and K control at ten research sites established during 2014.

Site[a]	Expected yield response[b]		Check yield[c]	Yield response to[d]		
	P	K		P only	K only	P and K
			(bu/acre)	-------------[Yield difference (*P*-value)] -------------		
NEREC-S14	No	No	171	+2 (0.86)	-3 (0.78)	--[e]
NEREC-S4	No	No	161	+1 (0.86)	+10 (0.04)	--
PTRS-F18	Yes	Yes	228	-1 (0.93)	-1 (0.90)	+5 (0.45)
PTRS-F5	Maybe	Yes	245	-6 (0.35)	0 (0.95)	+2 (0.72)
PTRS-I10	Maybe	Yes	208	+3 (0.60)	+9 (0.11)	+7 (0.15)
PTRS-MJC	No	Yes	183	-1 (0.78)	+4 (0.37)	-1 (0.84)
RREC-E	Maybe	Maybe	171	-2 (0.62)	0 (0.99)	-4 (0.26)
RREC-W	Yes	Yes	151	+6 (0.31)	+3 (0.60)	0 (0.99)
RRS-Clay	No	No	180	+1 (0.87)	0 (0.92)[f]	-1 (0.85)
RRS-Loam	Yes	Maybe	209	-5 (0.43)	-3 (0.67)	0 (0.93)

[a] Abbreviations include: NEREC,Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The letter or letters after the site abbreviation represent the field name

[b] Expected Response: Yes, soil-test level is Very Low or Low; Maybe, soil-test level is Medium; and No, soil-test level is Optimum or Above Optimum.

[c] Check yield, the mean yield of rice that received no P or K.

[d] Yield response: P only, single-degree-of-freedom contrast comparing the yield with no P or K to P fertilizer; K only, single-degree-of-freedom contrast comparing the yield with no P or K to K fertilizer; and P & K, single-degree-of-freedom contrast comparing the yield with no P or K to that of soybean fertilized with both P and K fertilizer.

[e] '--' indicates that the comparison was not possible.

[f] Comparison was made using plots that received the same P rate (60 lb P_2O5/acre) but different K rates.

Table 4. Site responses and accuracy of the soil-test prediction of rice yield response to fertilization at ten research sites in 2014 as defined by soil-test P (STP) and K (STK) level and the level of significance at which statistical comparisons were made.

		Total	Interpreted at $P \leq 0.05$			Interpreted at $P \leq 0.25$		
Nutrient	Soil test range[a]	sites	Increase	No change	Decrease	Increase	No change	Decrease
			Number of sites					
P	≤25	3	0	3	0	0	3	0
P	26-35	3	0	3	0	0	3	0
P	≥36	4	0	4	0	0	4	0
Overall STP accuracy (%)[b]			67			67		
K	≤90	5	0	5	0	1	4	0
K	91-130	2	0	2	0	0	2	0
K	≥131	3	1	2	0	1	2	0
Overall STK accuracy (%)[b]			56			62		

[a] Ranges are grouped as Suboptimal (≤25 ppm P and ≤90 ppm K, including the Very and Low levels in which a positive yield response is expected); Medium (26 to 35 ppm P and 91 to 130 ppm K, response is unpredictable meaning no yield increase or a slight increase is expected); and Optimal (≥36 ppm P and ≥131 ppm K including the Optimum and Above Optimum levels in which no yield increase or decrease expected)

[b] Accuracy calculated as the weighted average for the three soil-test ranges where the number of sites with the expected outcome (see footnote 'a') is divided by the number of sites.

Effects of Water-Saving Rice Cultivation Methods on Yield, Water Use, and Water-Use Efficiency

J.P. Gaspar, C.G. Henry, M.M. Anders, M. Duren, D. Hendrix, and A.P. Horton

ABSTRACT

Water available for irrigation is declining in many rice-growing regions around the world. Global populations continue to rise increasing crop production demand. Rice production systems must face the dilemma of maintaining or increasing yields with less water available to irrigate. Alternate wetting and drying (AWD) has shown to be an effective tool for water conservation in irrigated rice systems. Research on AWD practices is lacking and more information is needed to verify the success of AWD across varying soil types. More work is needed to develop clear recommendations for AWD irrigation practices in Arkansas. In this study we compared the effects of three different AWD regimes and a continuous flood management on rice yields and water-use efficiency (WUE) from a conventional variety (RoyJ) and a hybrid (XL753). The study was located in the northeast corner of the Mississippi delta rice-growing region in Arkansas and results were complicated by a high rainfall pattern in 2014; even with this complication, results indicated that AWD is a feasible water management practice for rice in Arkansas. For both varieties, all AWD regimes tested in this experiment were associated with a loss in yield, the hybrid cultivar had a higher yield than the conventional variety in all treatments. Water-use efficiency for the wettest AWD treatment was higher than the conventional flood treatments and the dryer AWD treatments. Differences in WUE between varieties approached significance differences, and suggests that the hybrid may have a higher WUE than the conventional cultivar.

INTRODUCTION

Water available for irrigation is declining in the main crop-growing regions. Irrigation is the largest component of fresh water use (Haddeland et al., 2014). High water use and drought are depleting water available for human use (Schewe et al., 2014). The alluvial aquifer in the east-central region of Arkansas is being depleted at unsustainable rates (ANRC, 2012). It has been estimated that 1.8 billion people will be living in regions with absolute water shortages and as much as two-thirds of the global population may be under water stress conditions by 2025 (FAO, 2013). Global populations continue to rise increasing crop production demand. Ray et al. (2013) estimates that global crop production needs will double by 2050 with an increase of 2.4% annually. Agricultural production systems must face the dilemma of maintaining or increasing yields with less water available to irrigate. Globally, rice production systems account for one-third of the total fresh water use (Bouman, 2009). Although rice and other crops have similar transpiration rates, substantially more water loss is associated with anaerobic rice cultivation practices than aerobic crop production systems due to soil percolation losses and evapotranspiration (Bouman, 2009). Water shortages coupled with the high costs associated with irrigation create the need to research alternate production methods that minimize water use while maximizing/maintaining yields. This can also be referred as water-use efficiency (WUE) measured as unit of grain per area divided by the volume of water applied per area. Such information will help guide rice producers that face the dilemma of water shortages first hand and provide viable alternative methods to minimize profit losses.

One such method that has been receiving increased attention in recent years is a rice production method referred to as alternate wetting and drying (AWD). Alternate wetting and drying combines the beneficial side effects of anaerobic rice cultivation (nematode and weed control), and aerobic cultivation practices (reduction in water use, grain toxin builds, and greenhouse gas emissions; Price et al., 2013). Alternate wetting and drying has shown to be an effective tool for water conservation in rice production systems. Zhang et al. (2009) found that AWD can lower water use in rice production by ~35%, while maintaining and even increasing rice yields relative to continual flood methods. Not only does this method reduce water use, but also it has been shown to be very effective in reducing greenhouse gas emissions that result from the brief aerobic periods (Yan et al.,2005; Feng et al., 2013), and at reducing buildup of arsenic in rice grains (Takahashi et al., 2004;Talukder et al., 2012).

In the literature, AWD methods in comparison to anaerobic rice cultivation have a range of results: no difference in yields, yield increases, and yield decreases. Davies et al. (2011) reviewed existing literature and found that mixed results on yield differences is likely dependent on severity of the soil moisture deficit during the dry-down events. This implies that target deficits will vary with differences in soil characteristics. An extensive study has been conducted in the Grand Prairie rice-growing region near Stuttgart, Ark. Linquist et al. (2015) found that in Dewitt silt loam soils, although yields were reduced less than 1% to 13%, the WUE was improved by 18% to 63% and AWD (early season) followed by flooding practices (late season) reduced water use by 18% while maintaining similar yields to that of flooded controls. Research on AWD practices is lacking in other regions of the state and across varying soil types, more work is needed in order to develop clear recommendations for AWD irrigation practices in the state of Arkansas. In this study we compared the effects of three different AWD regimes and a continuous flood management, on rice yields from a conventional variety (Roy J) and a hybrid variety (XL753) grown on Sharkey silty clay soils in the northeast corner of the Mississippi delta rice-growing region in Arkansas.

PROCEDURES

This study was conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark., in 2014. The soil type was a Sharkey silty clay with 3% sand, 33.1% silt, and 63.9 % clay (USDA-NRCS, 2013). Saturation, field capacity, and wilting point were calculated using Soil-Plant-Atmosphere-Water (SPAW) software's (USDA-ARS, Washington State University, Pullman Wash.) soil water characteristics with the soil equation of Saxton et al. (1986) and were determined to be 45.1%, 34.5%, and 13% volumetric soil water content (VWC), respectively. Rice was drill-seeded at a rate of 90 lb/acre for the conventional and 30 lb/acre for the hybrid on 8 May 2014 and plants emerged 18 May 2014. No irrigations were applied until the initial flood 11 July 2014, rainfall was sufficient for stand establishment. Plot sizes were 30 ft × 100 ft (3,000 sq ft), separated by dual packed levees to prevent water movement between plots. Plots were planted half with a conventional variety (RoyJ) and half with a hybrid (XL753) of which 800 sq ft of each variety in each plot was harvested on 9 October 2014.

The study involved four water management treatments replicated four times in a randomized complete block design. Treatments were: 1) flood (continuously flooded control), 2) AWD/16% VWC, 3) AWD/24% VWC, and 4) AWD/32% VWC. The AWD represents alternate wetting and drying followed by the volumetric soil water content. Thresholds and fields in each treatment were allowed to dry until a reflood was applied. Note: thresholds were selected based off previous studies, which had this soil type with a saturation point of 40.0% with triggers at 60% saturation (24% VWC) and 40% saturation (16% VWC) (Linquist et al., 2015); 32% VWC was selected based off of 80% saturation of the soil type with a saturation point of 40%. The plant available water of this soil is 21.5% VWC (difference between field capacity and wilting point). The actual deficits the trigger levels represent are deficits corresponding to 12% (32% VWC trigger), 49% (24% VWC trigger), and 86% (16% trigger). The highest deficit of 86% (or lowest VWC trigger of 16%) is near the wilting point, so it should be noted that this is a trigger level that is far too extreme for rice AWD. The authors caution other researchers to evaluate the available water-holding capacity of their soil types and use a managed allowable depletion that is reasonable for the soil type. Using the percent of field capacity, as has been done in other studies may not be appropriate to represent plant available water in different soil types.

All treatments were flooded to a 2- to 3-inch depth for 10 days (11-21 July) after the preflood nitrogen (i.e., urea) fertilizer application of 145 lb N/acre (8 July). In the flooded treatments, this flood depth was maintained throughout the growing season. After the initial ten day flood, the AWD treatments were allowed to dry until the soil moisture reached critical VWC for each respective treatment (16%, 24%, and 32% VWC at a depth of 2.5 inches) at which time the plots were re-flooded. Critical VWC thresholds were determined using a Dynamax TH300 soil moisture probe. Three measurements were collected from each replication in each treatment if the overall average of all the reps in that treatment reached the threshold or lower; a flood was applied to all plots of that treatment. Campbell Scientific CS655 water content reflectometer (Campbell Scientific, Inc., Logan, Utah) was also used in one of each AWD treatment's plots to track volumetric soil water content throughout the growing season at a depth of about 4.7 inches (12 cm). In the same three replicates, a Campbell Scientific CS451 pressure transducer (placed at the bottom of an 8- to 9-inch levee ditch) was also used to track the depth of the floods in the AWD treatments. Water inputs were also measured with 4-inch McCrometer propeller flowmeters in three out of the four replicates to determine the average total water usage for each water management treatment. Rain data was also collected using a Texas Electronics rain gage TE525 (Dallas, Texas). All logging sensor's inputs were processed and stored using a Campbell Scientific CR3000 data logger. At harvest, 800 sq ft were harvested with a small plot research combine with 4-foot header from each variety within each plot. The grain was weighed and moisture readings were taken and recorded. Yields in bushels per acre were calculated with a 12% moisture correction for each variety in water treatment plot and across all replicates.

Data Analysis

All data were analyzed using SYSTAT 13 and normality of all data was confirmed using a Shapiro-Wilk normality test. The water-use efficiency analysis of variance model assumption of homogeneity of variance was violated so a natural log transformation was conducted on the WUE response variables. Significant treatment effects were further analyzed using a Holm-Sidak method of mean comparison. Note: AWD/16%VWC was not included in the analysis because of lack of grain fill. In order to compare the differences in yields among treatments, an analysis of variance was used with a response variable, yield (bu/acre), and two treatments, Water treatment (three factor levels: flood, AWD/24% VWC, and AWD/32% VWC), Variety (two factor levels, XL753 and RoyJ), and a water treatment/variety interaction term. One of the AWD/24% VWC replicates also did not reach grain fill or maturity and so was not harvested. This replicate was treated as a missing value in the model. Water-use efficiency, bushels per acre-inch of water applied (bu/acre-inch), was calculated for all water treatments and varieties in plots that had flowmeters (three of the four replicates) by dividing yield per acre (bu/acre) by the inches of water applied per acre (acre-inch/acre). In order to compare the differences in WUE among water treatments and across varieties, a balanced analysis of variances was used in SYSTAT 13 with a response variable of WUE and two treatments: water treatment [three factor levels (three replicates each): flood, AWD/24% VWC, and AWD/32% VWC] and variety (two factor levels, XL753 and RoyJ).

RESULTS AND DISCUSSION

None of the AWD/16%VWC water treatment plots reached maturity indicating that a 16% VWC trigger point is far too low for use in AWD studies or applications in Sharkey silt clay soils. One of the AWD/24%VWC replicates also did not reach maturity suggesting that this replicate experienced more stress than the others in the 24%VWC treatment. However this replicate was one that did not have a flowmeter and water use was not recorded making it difficult to speculate the cause of the added stress to this replicate (only two of the three replicates had meters).

Yields

The interaction effect between water treatment and variety was not significant (P = 0.905). This indicated that varietal effects on yields and water treatment effects on yields are consistent across all water treatments and varieties, respectively. Significant effects of water treatment ($P < 0.001$) and variety ($P = 0.015$) on yield were observed. The mean comparison for water treatment indicated that all three treatments were significantly different from one another. The flood treatment (129.6 bu/acre) yielded on average 35.1 bu/acre more grain than AWD/32%VWC and 95.2 bu/acre more than AWD/24%VWC treatments independent of variety (Table 1). The AWD/32%VWC treatment (94.5 bu/acre) produced on average 60.1 bu/acre more grain than AWD/24%VWC (34.4 bu/acre). The mean comparison between varieties indicated that XL753 yielded on average 22.4 bu/acre more than RoyJ.

Water Use Efficiency

The interaction effect between water treatment and variety was not significant (P = 0.330). This indicated that varietal effects on WUE and water treatment effects on WUE are consistent across all water treatments and varieties, respectively. The varietal difference in WUE approached significance, $P = 0.052$, so the authors consider this supportive of a difference in WUE efficiency between varieties. Significant effect of water treatment ($P = 0.002$) on WUE was observed. The mean comparison indicates that AWD/32%VWC treatment had the higher grain to water use ratio than both of the other AWD water treatments (Table 2). There was no significant difference in WUE between the Flood and AWD/24% VWC treatments (Table 2). The data indicate that on average AWD/32%VWC's grain to water use ratio was 1.28 to 0.98 bushels of grain/acre-inch of water applied, greater than AWD/24%VWC and flood treatment, respectively. The deviation between varieties WUE means can be explained from examining the least square mean WUE for each variety within each water treatment. Despite having similar amounts of water applied across replicates (data not shown), RoyJ in the AWD/24%VWC treatment had a considerably low WUE relative to XL753 due to the very low average yields for RoyJ in that treatment. More evidence explaining the approaching significant difference in WUE between varieties can be seen from the overall difference in yield observed, across all water treatments, between RoyJ and XL753 as well as in the varietal yields between each treatment (Table 3). The drop in varietal yields from the flooded control to the AWD/32%VWC within variety was the same for XL753 and RoyJ at 27% yield loss from flood control average for each respective variety (Table 3). The drop in varietal yields from the flooded control to the AWD/24%VWC within variety was 67% for XL753 and 81% for RoyJ.

Observational Results

The average water used in each water treatment was highest for the flood, followed by AWD/32%VWC, AWD/24%VWC and AWD/16%VWC (Table 3). After the initial ten day flood, the 16%VWC treatments never reached trigger point and were not re-flooded (Table 3). The AWD/24%VWC reached trigger point once 37 days after termination of the initial flood and the AWD32%VWC trigger was met twice 9 days after termination of the initial flood, then again 26 days later (Figs. 1 and 2). This year had substantial amounts of rain totaling 18 inches during the growing season and 10.3 inches during the irrigation period. In many instances just as plots were drying down toward the trigger point, rains brought the VWC reading back up increasing time between irrigations (Fig. 1). This can also be seen in the water-depth data for several rain events (Fig. 2). Aside from the amount of rainfall this year, the water applied to all treatments was extremely high (Table 3). Due to the difficulties in pulling levees in this soil, the levee ditch depth ranged 8 to 9 inches, which could have contributed to the high water usage. By examining the levee ditch water-depth data it appears as if there were leakage issues seen from the sharp rate of drawdown just following a flooding event (Fig. 2). Speculatively speaking, leakage issues could have been caused by soil cracking resulting in deep percolation losses and/or seepage across the levees; more investigation is needed to explain. Bouman and Tuong (2001) found that AWD methods may lead to increased water use due to drying cycles leading to soil shrinkage and cracking. Data like soil moistures across the levees after a flooding event would be needed to determine if leakage across the levees was occurring.

SIGNIFICANCE OF FINDINGS

The flood treatment yielded the most grain relative to AWD/32%VWC and AWD/24%VWC treatments across both varieties. Overall, XL753 yielded significantly more grain than RoyJ (Table 1). On average WUE for the AWD/32%VWC treatment was greater than AWD/24%VWC and the flood treatments. Difference in WUE averages between varieties approached significance, and suggests that XL753 may have a higher WUE than RoyJ. Overall water use was extremely high and extreme decreases in yield averages between water treatments gives further evidence that AWD methods as well as thresholds will vary depending on soil characteristics in which the practice is implemented. Furthermore, thresholds should be calculated from plant available water characteristics of the soil, and these thresholds have yet to be determined for Arkansas soil types. More AWD research is needed to determine applicable thresholds for AWD methods on a wide variety of soil types in order to establish useful guidelines for farmers that wish to implement this water conservation practice.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board for financial support and the staff at the Northeast Research and Extension Center in helping to conduct this study.

LITERATURE CITED

ANRC. Arkansas Natural Resources Commission 2012. Arkansas Groundwater Protection and Management Report for 2011. Little Rock, Ark.

Bouman, B.A.M. and T.P. Tuong. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agricultural Water Management. 49:11-30.

Bouman, B.A.M. 2009. How much water does rice use. Rice Today. 8:28-29.

Davies, W.J., J. Zhang, J. Yang, and I.C. Dodd. 2011. Novel crop science for water-limited agriculture. J. Agri. Sci. 149:123-131.

FAO. Food and Agriculture Organization of the United Nations. 2010. Hot Issues: Water Scarcity. Water and poverty, an issue of life and livelihoods. Land and Water Division. Accessed 23 Jan. 2015. Available at: http://www.fao.org/nr/water/issues/scarcity.html.

Feng, J., C.Q. Chen, Y. Zhang, Z. Song, A. Deng, C. Zheng, and W. Zhang. 2013. Impacts of cropping practices on yield-scaled greenhouse gas emissions from rice fields in China: A meta-analysis. Agriculture Ecosystems & Environment. 164:220-228.

Haddeland, I., J. Heinke, H. Bieman, S. Eisner, M. Flörke, N. Hanasaki, M. Konzmann, F. Ludwig, Y. Masaki, J. Schewe, T. Stacke, Z.D. Tessler, Y. Wada, and D. Wisser. 2014. Global water resources affected by human interventions and climate change. Proc. National Academy of Sciences of the United States of America, 111:3251-3256.

Linquist, B.A., M.M. Anders, M.A. Adviento-Borbe, R.L. Chaney, L.L. Nalley, E.F.F. da Rosa, and C. van Kessel. 2015. Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems. Global Change Biology 21:407-417.

Price, A.H., G.J. Norton, D.E. Salt, O. Ebenhoeh, A.A. Meharg, C. Meharg, M. Rafiqul Islam, R. N. Sarma, T. Dasgupta, A.M. Ismail, K.L. McNally, H. Zhang, I.C. Dodd, and W.J. Davies. 2013. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? Food and Energy Security. 2:120-129.

Ray, D.K., N.D. Mueller, P.C. West, and J.A. Foley. 2013. Yield trends are insufficient to double global crop production by 2050. PLoS ONE, 8:e66428.

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036.

Schewe, J., J. Heinke, D. Gerten, I. Haddeland, N.W. Arnell, D.B. Clark, R. Dankers, S. Eisner, B. M. Fekete, F.J. Colón-González, S.N. Gosling, H. Kim, X. Liu, Y. Masaki, F.T. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski, and P. Kabat. 2014. Multimodel assessment of water scarcity under climate change. Proc. National Academy of Sciences of the United States of America, 111:3245-3250.

Takahashi, Y., R. Minamikawa, K.H. Hattori, K. Kurishima, N. Kihou, and K. Yuita. 2004. Arsenic behavior in paddy fields during the cycle of flooded and non-flooded periods. Environmental Science & Technology, 38:1038-1044.

Talukder, A.S.M.H.M., C.A. Meisner, M.A.R. Sarkar, M.S. Islam, K.D. Sayre, J.M. Duxbury, and J.G. Lauren. 2012. Effect of water management, arsenic and phosphorus levels on rice in a high arsenic soilwater system: II. Arsenic uptake. Ecotoxicology and Environmental Safety. 80:145-151.

USDA-NRCS. United States Department of Agriculture Natural Resources Conservation Service. 2013. Welcome to Web Soil Survey (WSS). Accessed January 2014. Available at: http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Yan, X., K. Yagi, H. Akiyama, and H. Akimoto. 2005. Statistical analysis of the major variables controlling methane emission from rice fields. Global Change Biology. 11:1131-1141.

Zhang, H., Y. Xue, Z. Wang, J. Yang, and J. Zhang. 2009. Alternate wetting and moderate soil drying improves root and shoot growth in rice. Crop Science. 49:2246-2260.

Table 1. Yield differences between water treatment ($P < 0.001$) and variety ($P = 0.015$) revealed by analysis of variance. Least square means for rice yields for water treatment and variety, with Shapiro-Wilk method for mean comparison of significant groupings.

Water treatment	SEM[†]	Average yield
		(bu/acre)
Flood	6.781	129.6 a[§]
AWD/32%VWC[‡]	6.781	94.5 b
AWD/24%VWC	7.83	34.4 c
AWD/16%VWC	NA	0
Variety		
XL 753	5.84	97.4 a
RoyJ	5.84	75 .0 b

† SEM = standard error of the mean.

‡ Indicates treatment not used in the model. VWC = volumetric soil water content.

§ Means within a column followed by different letters are significantly different at the $P = 0.05$ level.

Table 2. Water-use efficiency (WUE) differences revealed by analysis of variance for the factor level differences in WUE for water treatment ($P < 0.002$) and variety ($P = 0.052$)[†].

	Water use efficiency
	(bu/acre-inch)
Water treatment	
AWD/32%VWC[‡]	2.00 a[§]
Flood	1.02 b
AWD/24%VWC	0.72 b
AWD/16%VWC[¶]	NA
SEM[#] = 1.17	
Variety	
XL753	1.38 a
RoyJ	0.94 a
SEM = 1.13	

[†] Back-transformed Least square means for WUE in bushels per acre-inch, for water treatment and variety, with Shapiro-Wilk method for mean comparison significant groupings. (Note: varietal WUE means approached significance but no true difference in mean WUE was detected between varieties.)
[‡] AWD = alternate wetting and drying; VWC = volumetric soil water content.
[§] Means within a column followed by different letters are significantly different at the $P = 0.05$ level.
[¶] Indicates treatment not used in the model.
[#] SEM = standard error of the mean.

Table 3. Summary of the water usage (applied) and number of irrigations after the initial 10-day flood cycle[†].

Treatment	No. of reflood after initial flood	Water use	Yield	Varietal WUE
		(acre-inches/acre)	(bu/acre)	(bu/acre-inch)
Flood	13	132.8		
XL753			142.0 a[‡]	1.13 b
RoyJ			117.3 a	0.93 b
AWD/32%VWC[§]	2	45.8		
XL753			103.2 b	2.19 a
RoyJ			85.9 b	1.82 a
AWD/24%VWC	1	42.9		
XL753			47.0 c	1.06 b
RoyJ			21.8 c	0.49 b
AWD/16%VWC	0	21.7		
XL753			NA	NA
RoyJ			NA	NA

[†] The water-use efficiency ratings and varietal yield values came from water treatment by variety interaction term's back-transformed least square means from the analysis of variance of water-use efficiency and yield, respectively. (Note: interaction in both models was not significant so none of the values listed below for yield or efficiency are significantly different between varieties within each water treatment.)
[‡] Means within a column followed by different letters are significantly different at the $P = 0.05$ level.
[§] AWD = alternate wetting and drying; VWC = volumetric soil water content.

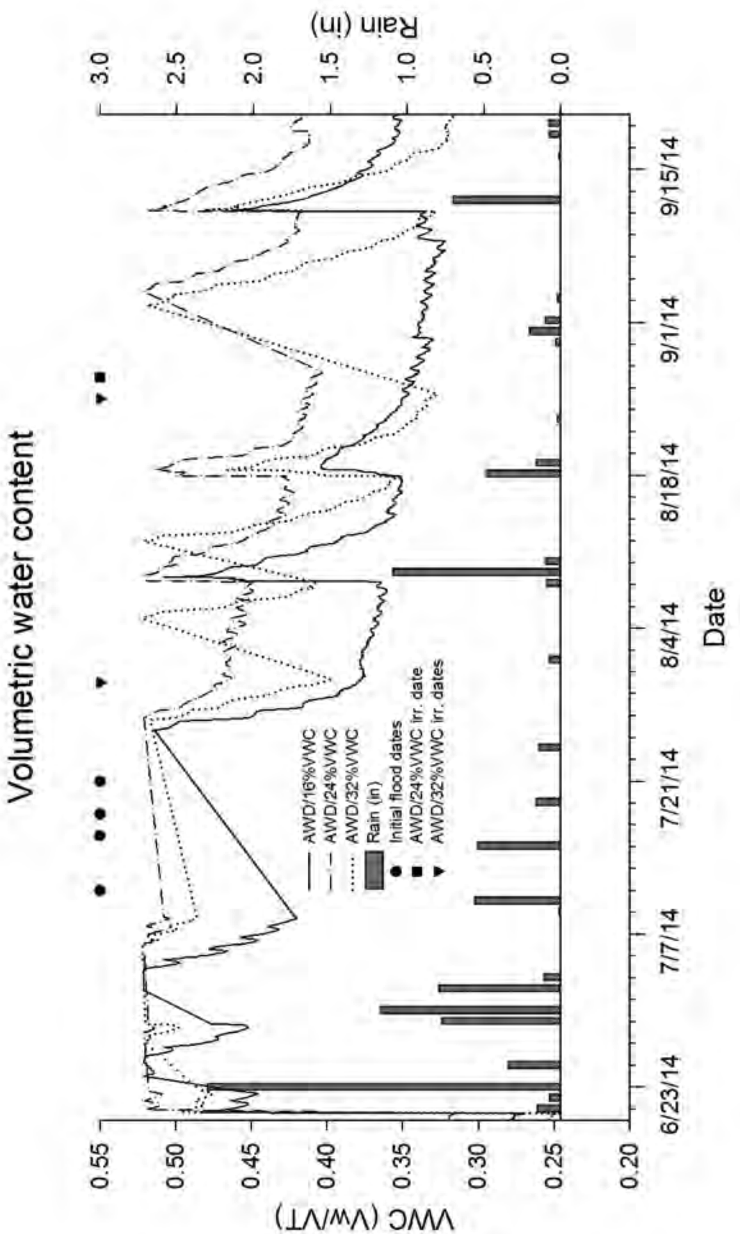


Fig. 1. Mapping volumetric soil water content (VWC) response to rain and irrigation event through a graphical view of volumetric water content for one replicate of each alternate wetting and drying (AWD) water treatment throughout the season with rain amounts/event as well as irrigation dates overlaid.

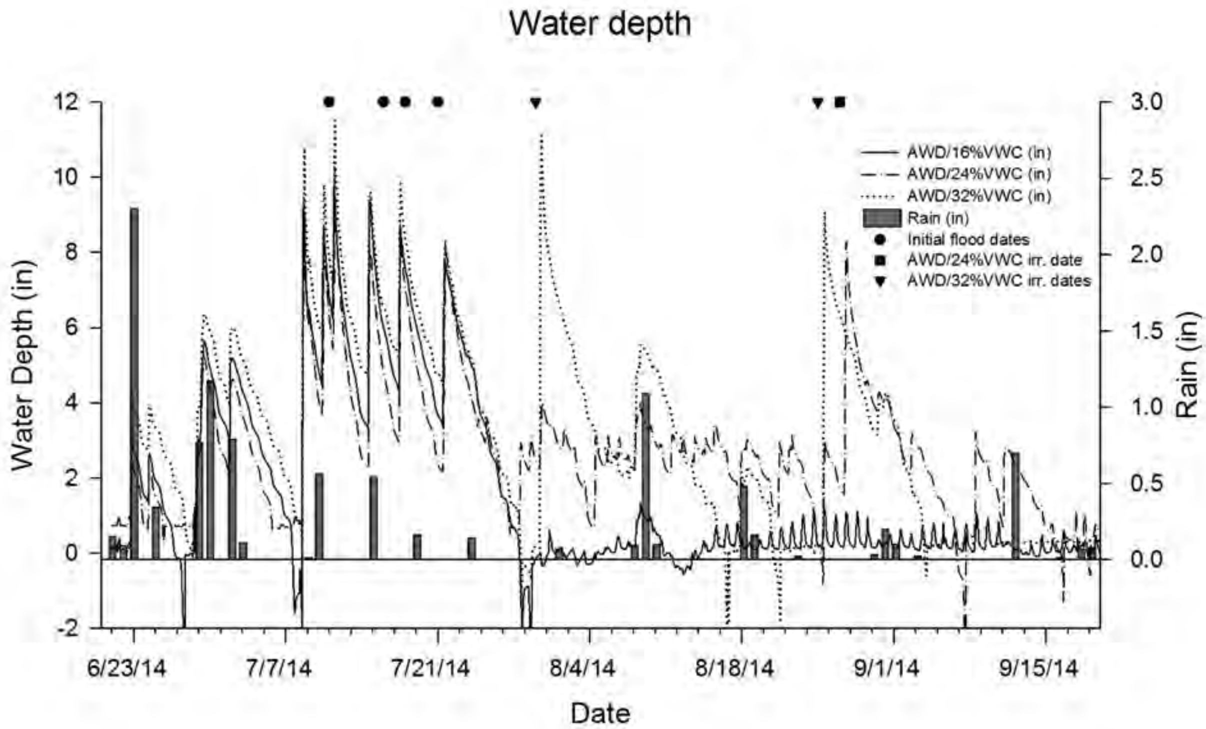


Fig. 2. Mapping bar ditch water depth response to rain and irrigation event through a graphical view of bar ditch depth of one replicate for each alternate wetting and drying (AWD) water treatment throughout the season with rain amounts/ event as well as irrigation dates overlaid. Note levee ditch range is 8 to 9 inches deep.

Arkansas Rice Performance Trials, 2012-2014

J.T. Hardke, D.L. Frizzell, E. Castaneda, K.A.K. Moldenhauer, X. Sha, G. Berger, Y. Wamishe, R.J. Norman, M.M. Blocker, J.A. Bulloch, T. Beaty, R. Mazzanti, R. Baker, W. Kirkpatrick, and M. Duren

ABSTRACT

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program and commercially available cultivars from public and private breeding programs. The trials are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARPTs were conducted at five locations during 2014. Averaged across locations, grain yields were highest for the commercial cultivars RiceTec XL753, Caffey, Jupiter, and LaKast. Cultivars with the highest head rice yield during 2014 included Antonio, Mermentau, Clearfield (CL) 151, and CL152.

INTRODUCTION

Cultivar selection is likely the most important management decision made each year by rice producers. This choice is generally based upon past experience, seed availability, agronomic traits, and yield potential. When choosing a rice cultivar, grain yield, milling yield, lodging potential, maturity, disease susceptibility, seeding date, field characteristics, the potential for quality reductions due to pecky rice, and market strategy should all be considered. Data averaged over years and locations are more reliable than a single year of data for evaluating rice performance for such important factors as grain and milling yields, kernel size, maturity, lodging resistance, plant height, and disease susceptibility.

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, Mississippi, and Missouri with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices.

PROCEDURES

The five locations for the 2014 ARPTs included the Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; the Turner farm in Clay County (CLAY); and the Whitaker farm in Desha County (DESHA). Ninety entries, which were either promising breeding lines or established cultivars, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, CLAY, and DESHA on 2 May, 6 May, 7 May, 23 April, and 5 May, respectively. Pure-line varieties were drill-seeded at a rate of 75 lb seed/acre in plots eight rows (7-inch spacing) wide and 15 ft in length. Hybrid entries were sown into the same plot configuration using a reduced seeding rate of 30 lb seed/acre. Cultural practices varied somewhat among the ARPT locations but overall were grown under conditions for high yield. Phosphorus and potassium fertilizers were applied before seeding at the RREC and PTRS locations. Nitrogen was applied to ARPT studies located on experiment stations at the 4- to 5-lf growth stage in a single preflood application of 120 lb N/acre on silt loam soils and 150 lb N/acre on clay soils using urea as the N source. The permanent flood was applied within 2 days of preflood-N application and maintained throughout the growing season. At maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain removed for grain quality and milling determinations. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. The dried rice was milled to obtain percent head rice and percent total white rice (%HR - %TR). Each location of the study was arranged in a randomized complete block design with four replications.

RESULTS AND DISCUSSION

The 3-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2012-2014 are listed in Table 1. The top five yielding cultivars, averaged across location and the 3-study years were: RiceTec XL753, Roy J, Caffey, LaKast, and Jupiter with grain yields of 233, 200, 199, 192, and 190 bu/acre, respectively. Two experimental lines, the long-grain AREX1084 and the medium-grain AREX1021, also did well with grain yield averages of 204 and 212 bu/acre, respectively. In regard to percent head rice and percent total white rice (%HR - %TR), Antonio, CL151, CL152, CL172, Mermentau, and Roy J had the highest overall average milling yields from 2012-2014.

Selected agronomic traits, grain yield, and milling yields from the 2014 ARPT are shown in Table 2. Due to severe lodging, harvest data was not used for the NEREC location. RiceTec XL753 was the only commercial cultivar to maintain a grain yield above 200 bu/acre at all locations. Other notable cultivars in 2014 included Caffey, Jupiter, LaKast, RiceTec CLXL745, Roy J, RiceTec CLXL729, and CL151. Milling yield, averaged across locations and cultivars, was 62-70 (%HR - %TR) during 2014. The long-grain cultivars Antonio, CL172, Mermentau, CL151, and CL152 had the highest milling yields of all commercial entries, averaging 66-72, 66-71, 66-71, 65-71, and 65-71, respectively, across all locations.

The most recent disease ratings for each cultivar are listed in Table 3. Ratings for disease susceptibility should be evaluated critically to optimize cultivar selection. These ratings should not be used as an absolute predictor of cultivar performance with respect to a particular disease in all situations. Ratings are a general guide based on expectations of cultivar reaction under conditions that strongly favor disease; however, environment will modify the actual reaction in different fields.

Growers are encouraged to seed newly released cultivars on a small acreage to evaluate performance under their specific management practices, soils, and environment. Growers are also encouraged to seed rice acreage in several cultivars to reduce the risk of disease epidemics and environmental effects. Cultivars that have been tested under Arkansas growing conditions are more likely to reduce potential risks associated with crop failure.

SIGNIFICANCE OF FINDINGS

Data from this study will assist rice producers in selecting cultivars suitable to the wide range of growing conditions, yield goals, and disease pressure found throughout Arkansas.

ACKNOWLEDGMENTS

The Arkansas Rice Performance Trials are supported through grower check-off funds administered by the Arkansas Rice Research and Promotion Board. We wish to thank the following people for their dedication to making the ARPT possible each year: Bethany Berger, Shawn Clark, and Chuck Pipkins.

Table 1. Results of the Arkansas Rice Performance Trials

Cultivar	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight	Milled kernel weight[d]	Chalky kernels[d]
		(rating)	(days)	(inches)	(lb/bu)	(mg)	(%)
Antonio	L	2.0	83	37	42.1	20.50	1.99
Caffey	M	2.2	85	38	42.3	23.83	1.38
CL111	L	2.1	81	38	41.9	21.13	0.94
CL151	L	1.6	83	39	41.6	19.78	1.93
CL152	L	1.7	85	37	41.7	18.03	1.55
CL172	L	1.0	84	35	41.6	21.50	1.39
Colorado	L	3.4	81	38	41.2	22.05	1.88
Jazzman-2	L	2.1	84	38	41.5	18.86	0.71
Jupiter	M	2.9	86	38	41.7	20.83	1.72
LaKast	L	2.5	83	42	41.6	21.95	0.71
Mermentau	L	1.4	83	37	41.6	19.7	1.90
RTCLXL729	L	3.9	83	43	41.4	20.45	1.97
RTCLXL745	L	4.1	80	43	41.6	21.56	1.09
RTXL753	L	2.5	81	42	41.9	21.32	1.83
Roy J	L	1.0	88	41	41.7	21.00	0.76
Taggart	L	1.8	87	44	41.7	23.00	0.83
Wells	L	2.1	85	41	42.0	21.56	1.03
AREX1021	M	1.5	79	38	41.5	22.75	1.95
AREX1084	L	1.8	84	41	41.4	21.70	1.10
Mean		2.1	84	39	41.7	21.13	1.402

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

[d] Data from 2011-2013. Based on weight of 1,000 kernels. Data from Riceland Grain Quality Lab.

[e] Data from Clay and Desha counties, and the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rice Research and Extension Center (RREC) only.

averaged across the three-year period of 2012-2014.

Milling yield by year				Grain yield by year			
2012	2013	2014[e]	Mean	2012	2013	2014[e]	Mean
------------------- (%HR-%TR) -----------------				-------------------- (bu/acre) --------------------			
64-71	65-70	66-72	65-71	187	176	164	176
60-69	58-67	57-69	58-68	197	198	202	199
62-71	64-69	63-71	63-70	169	162	170	167
63-71	65-70	65-71	64-71	191	169	190	184
63-71	66-70	65-71	65-71	179	153	144	158
62-71	66-70	66-71	64-71	214	174	165	184
61-70	63-69	63-70	62-70	163	143	174	160
63-70	66-69	64-70	64-70	157	151	170	159
61-68	61-66	59-68	60-67	197	178	196	190
61-72	63-70	62-71	62-71	196	186	193	192
65-71	65-69	66-71	65-70	199	173	168	180
59-70	62-69	61-70	61-70	184	188	191	188
57-72	61-69	61-71	60-71	185	165	193	181
57-71	60-70	57-71	58-71	229	225	246	233
64-72	63-70	62-70	63-71	219	188	192	200
56-71	62-69	60-70	59-70	187	186	187	186
54-71	62-70	57-70	58-70	194	178	182	185
54-68	58-67	55-69	56-68	224	193	220	212
----	62-68	61-69	62-69	----	203	206	204
60-71	63-69	62-70	62-70	191	178	185	184

Table 2. Results of the Arkansas Rice

Cultivar	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight
		(rating)	(days)	(inches)	(lb/bu)
Antonio	L	1.0	86	37	42.5
Caffey	M	1.6	87	38	42.3
CL111	L	1.4	85	37	42.5
CL151	L	1.8	86	38	42.4
CL152	L	1.0	88	36	42.2
CL163	L	1.8	88	38	42.1
CL172	L	1.0	87	35	42.3
CL271	M	1.6	89	37	42.1
Colorado	L	2.2	85	37	42.6
Jazzman-2	L	1.4	87	39	42.3
Jupiter	M	2.6	87	38	41.6
LaKast	L	1.4	87	40	42.2
Mermentau	L	1.2	86	37	42.5
RTCLXL729	L	1.8	87	42	42.4
RTCLXL745	L	2.4	83	42	42.8
RTXL753	L	1.4	84	41	42.9
Roy J	L	1.0	90	41	42.2
Taggart	L	1.4	89	43	42.4
Wells	L	1.2	88	42	42.4
AREX1021	M	2.0	83	39	42.1
AREX1084	L	1.6	87	41	42.4
Mean		1.6	87	39	42.3

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

[d] Studies were located in Clay and Desha counties and at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rice Research and Extension Center (RREC).

Performance Trials at four locations during 2014.

	Grain yield by location[d] and planting date				
Milling yield	Clay 23 April	Desha 5 May	PTRS 6 May	RREC 2 May	Mean
(%HR-%TR)	------------------------	------------------------	(bu/acre)	------------------------	------------------------
66-72	174	162	169	152	164
57-69	219	174	217	195	202
63-71	178	173	183	146	170
65-71	194	195	196	176	190
65-71	147	146	156	127	144
63-70	182	165	174	176	174
66-71	193	148	169	150	165
58-70	201	165	178	164	177
63-70	169	177	190	160	174
64-70	168	172	179	159	170
59-68	163	187	220	215	196
62-71	205	190	205	172	193
66-71	179	160	177	158	168
61-70	187	196	207	173	191
61-71	200	193	198	181	193
57-71	254	253	250	227	246
62-70	208	184	197	178	192
60-70	213	177	189	168	187
57-70	196	179	181	171	182
55-69	226	217	215	221	220
61-69	207	207	202	206	206
62-70	192	182	192	174	185

Table 3. Rice cultivar reactions[a]

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot
Antonio	S	S	--	MS	MS
Caffey	MS	MR	--	S	R
Cheniere	S	VS	VS	VS	S
CL111	VS	MS	S	VS	VS
CL151	S	VS	VS	VS	S
CL152	S	VS	S	S	MR
CL163	MS	--	--	MS	--
CL172	MS	MR	--	MS	--
CL261	MS	VS	S	VS	S
CL271	S	MR	--	MS	MR
Cocodrie	S	S	VS	S	S
Della-2	S	R	--	S	MS
Francis	MS	VS	MR	VS	S
Jazzman	MS	S	S	S	S
Jazzman-2	VS	S	--	VS	MR
Jupiter	S	S	S	MR	MS
LaKast	S	S	MS	S	MS
Mermentau	S	S	VS	MS	MS
Rex	S	S	S	S	MS
Roy J	MS	S	S	S	MR
RTCLXL729	MS	R	MS	MR	MS
RTCLXL745	S	R	R	MR	MS
RTCLXP756	MS	--	--	--	--
RTXL723	MS	R	S	MR	MS
RTXL753	MS	R	MS	MR	--
RTXP754	MS	--	--	--	--
Taggart	MS	MS	R	MS	MS
Wells	S	S	S	S	S

[a] Reaction: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; and VS = Very Susceptible. Reactions were established from both historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist.

to diseases (2014).

Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath Spot
S	S	MS	MS	--	--
--	--	MS	--	--	--
S	S	S	MR	MS	--
VS	S	S	MS	S	--
VS	S	S	MR	S	--
--	VS	S	--	--	--
--	--	--	--	--	--
--	--	S	--	--	--
VS	MS	S	MS	MS	--
--	--	--	--	S	--
VS	S	S	MR	S	--
--	--	--	--	--	--
S	VS	S	MS	S	--
S	MS	S	MS	MS	--
--	S	S	--	--	--
VS	MS	MS	MS	MR	--
S	S	S	MS	MS	S
--	S	S	MS	--	--
S	S	S	MR	S	--
S	VS	S	MR	MS	--
S	MS	S	S	S	--
S	MS	S	S	S	--
--	--	S	--	S	--
S	MS	S	MS	S	--
--	MS	S	--	S	--
--	--	S	--	S	S
S	S	S	MS	MS	--
VS	S	S	MS	MS	--

Grain Yield Response of Five New Rice Varieties to Nitrogen Fertilization

R.J. Norman, T.L Roberts, J.T. Hardke, N.A. Slaton, K.A.K. Moldenhauer, D.L. Frizzell, M.W. Duren, E. Castaneda-Gonzalez, and A.M. Fulford

ABSTRACT

The variety × nitrogen (N) fertilizer rate studies determine the proper N fertilizer rate for the new rice varieties across three locations, two silt loams and a clay soil, in the Arkansas rice-growing region. The five rice varieties studied in 2014 were: LaKast, Mermentau, and Horizon Ag's Clearfield (CL)163, CL172, and CL271. Cool, wet weather and muddy soil conditions delayed planting until early May, but surprisingly rice grain yields in commercial fields in Arkansas in 2014 tied the record set in 2013. Lodging and substandard yields were an issue at only one location in 2014 and they were due to severe storms with high winds which resulted in lodging and muddy conditions of the clay soil not allowing harvest to be conducted in a timely manner. This was the first year Horizon Ag's CL163, CL172, and CL271 were in Variety × N study and thus there is not enough data to make a recommendation at this time. The 3 years of results collected on LaKast indicated the variety should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on clay soils. The results collected on Mermentau indicated an N rate range would be the best recommendation. When Mermentau is grown on silt loam soils, a total N rate range of 135 to 150 lb N/acre should be applied in a two-way split application of 90 to 105 lb N/acre at preflood and 45 lb N/acre at midseason; and when grown on clay soils, the preflood-N rate should be increased by 30 lb N/acre.

INTRODUCTION

The variety × N fertilizer rate studies measure the grain yield performance of the new rice varieties over a range of N fertilizer rates on representative clay and silt loam soils and determines the proper N fertilizer rates to maximize yield on these soils under the climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Five new rice varieties were entered and studied in 2014 at three locations as follow: Arkansas entered the standard stature, long-grain LaKast; Louisiana entered the semidwarf, long-grain Mermentau; and Horizon Ag entered the Clearfield standard stature, long-grain variety CL163 (which has higher amylose content for processing quality) in cooperation with Mississippi, the standard stature, long-grain CL172 in cooperation with Arkansas, and the semidwarf, medium-grain CL271 in cooperation with Louisiana. Clearfield rice varieties are tolerant to the broad spectrum herbicide imazethapyr (Newpath).

PROCEDURES

Locations where the variety × N fertilizer rate studies were conducted and corresponding soil series are as follows: Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); Pine Tree Research Station (PTRS), near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized at all locations for all the rice varieties studied was a randomized complete block with four replications. A single preflood-N fertilizer application was utilized for all varieties and was applied as urea on to a dry soil surface at the 4- to 5-lf stage. The preflood-N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/acre. The studies on the two silt loam soils at the PTRS and the RREC received the 0 to 180 lb N/acre fertilizer rates and the studies on the clay soil at the NEREC received the 0 to 210 lb N/acre N rates with the 60 lb N/acre rate omitted. Rice usually requires about 20 to 30 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. All of the rice varieties were drill-seeded on the silt loams and clay soil at rates of 73 and 91 lb/acre, respectively, in plots 9 rows wide (row spacing of 7 in.), 15 ft in length. Pertinent agronomic dates and practices at each location are shown in Table 1. The studies were flooded at each location when the rice was at the 4- to 5-lf stage and within 2 days of preflood-N fertilization. The studies remained flooded until the rice was mature. At maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bushel (bu)/acre at 12% moisture. A bushel of rice weighs 45 pounds (lb). Statistical analyses were conducted with SAS and mean separations were based upon Fisher's protected least significant difference test ($P = 0.05$) where appropriate (Tables 2-7). Also, the linear relationship between rice grain yield and fertilizer N rate was examined for each year, location, and cultivar combination using PROC REG of SAS v. 9.3 (SAS Institute, Inc., Cary, N.C.;

Figs. 1-6). Rice grain yield response to fertilizer N rate was positive and curvilinear (i.e., quadratic) as indicated by the significance ($P < 0.05$) of the regression model. For each year, location, and cultivar combination the 95% relative grain yield (RGY) was identified and the corresponding fertilizer N rate required to achieve 95% RGY was calculated by setting the dependent variable (i.e., grain yield) equal to 95% RGY and solving the regression equation for the independent variable (i.e., fertilizer N rate).

RESULTS AND DISCUSSION

A single preflood-N application method was adopted in 2008 in the variety × N fertilizer rate studies due to the rising cost of N fertilizer and the preference of the short stature and semidwarf rice plant types currently being grown. The currently grown rice varieties typically reach a maximum yield with less N when the N is applied in a single preflood application compared to a two-way split application. Usually the rice varieties require 20 to 30 lb N/acre less when the N is applied in a single preflood application compared to a two-split application where the second split is applied between beginning internode elongation and 0.5-in. internode elongation. Thus if 150 lb N/acre is recommended for a two-way split application, then 120 to 130 lb N/acre is recommended for a single preflood-N application. Conditions critical for use of the single, optimum preflood-N application method are: the field can be flooded timely, the urea is treated with the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) or ammonium sulfate used, unless the field can be flooded in 2 days or less for silt loam soils and 7 days or less for clay soils, and a 2- to 4-inch flood depth is maintained for at least 3 weeks following flood establishment.

In most years, the silt loam soil at the RREC has the largest amount of plant-available/readily available native N, followed by the silt loam soil at the PTRS, and then the clay soil at the NEREC. Thus, most rice varieties require a lower N fertilizer rate to maximize grain yield at the RREC compared to at the PTRS or NEREC, and usually a little less at the PTRS than at the NEREC. Pertinent agronomic information such as planting, herbicide, fertilization, and flood dates are shown in Table 1. Grain yields in the 2014 variety × N rate studies at the PTRS and RREC were typical of most normal years even though cool, wet weather and muddy soil conditions caused a delay in planting until early May. Lodging and substandard yields were an issue on the clay soil at the NEREC due to steady rains and high winds at harvest time that resulted in lodging and a delay in harvest.

Horizon Ag's CL163 lodged severely at the NEREC in 2014, like most of the other varieties, and thus the data from this location is of no use in determining the proper N fertilizer rate for the variety (Table 2; Fig. 1). When grown on the silt loam soils, CL163 had a maximum grain yield of 197 bu/acre at the PTRS when 120 lb N/acre was applied preflood and 186 bu/acre at the RREC when 150 lb N/acre was applied preflood (Table 2). This variety obtained 95% of the maximum yield (PTRS = 187 bu/acre and RREC = 177 bu/acre) on both silt loam soils when only 93 lb N/acre was applied preflood (Fig. 1). It did not significantly increase in grain yield when > 120 lb N/acre was applied preflood at the PTRS and RREC in 2014 (Table 2). Horizon Ag's CL163 appeared to have a stable yield over three or four N rates around the N rate required to maximize yield. This was the first year CL163 was in the variety × N fertilizer rate studies and one to two more years of data will be required before an N-rate recommendation can be made.

There was very little lodging of CL172 at the NEREC, but the results are still suspect because CL172 only obtained a maximum yield of 147 bu/acre when 150 lb N/acre was applied preflood to the clay soil at NEREC (Table 3; Fig. 2). It achieved 95% of the maximum yield at the NEREC when 140 lb N/acre was applied preflood. When grown on the silt loam soil at the PTRS, CL172 obtained a grain yield of 192 bu/acre when 150 lb N/acre was applied preflood and did not significantly increase in yield (194 bu/acre) when up to 180 lb N/acre was applied (Table 3). This variety achieved 95% of the maximum yield at the PTRS when 119 lb N/acre was applied preflood (Fig. 2). On the silt loam soil at the RREC, CL172 obtained a maximum yield of 194 bu/acre when 120 lb N/acre was applied preflood, but did not significantly increase in yield above the 190 bu/acre obtained when 90 lb N/acre was applied preflood (Table 3). It achieved 95% of the maximum yield at the RREC when only 70 lb N/acre was applied preflood (Fig. 2). Although this was only the first year CL172 was studied at all three locations in the variety × N fertilizer rate studies, CL172 appears to have a stable yield over a wide range of N rates once the N rate to achieve maximum yield is approached and exceeded. One to two more years of data will be required before an N-rate recommendation can be made for CL172.

The medium-grain CL271 experienced severe lodging at NEREC and thus the data from this location is of no use in determining the proper N fertilizer rate for the variety (Table 4; Fig. 3). When grown on the silt loam soil at the PTRS, CL271 obtained a grain yield of 203 bu/acre when 120 lb N/acre was applied preflood and did not significantly increase in yield (209 bu/acre) when up to 180 lb N/acre was applied (Table 4). Horizon Ag's CL271 achieved 95% of the maximum yield at the PTRS when 114 lb N/acre was applied preflood (Fig. 3). On the silt loam soil at the RREC, CL271 obtained a maximum yield of 196 bu/acre when 150 lb N/acre was applied preflood, but did not significantly increase in yield above the 189 bu/acre obtained when 90 lb N/acre was applied preflood (Table 4). It achieved 95% of the maximum yield at the RREC when 88 lb N/acre was applied preflood (Fig. 3). In the first year of testing, CL271 had a stable yield over a wide range of N rates once the N rate to achieve maximum yield was approached and exceeded. One to two more years of data will be required before an N-rate recommendation can be made for CL271.

LaKast lodged severely at the NEREC in 2014 and thus the data from this location is of no use in determining the proper N fertilizer rate for the variety (Table 5; Fig. 4). Studies (Norman et al., 2013; 2014; Fig. 4) of the effect of N rate on the grain yield of LaKast on the clay soil at NEREC in previous years reported maximum yields of over 200 bu/acre when 120 to 180 lb N/acre were applied preflood. LaKast achieved 95% of the maximum yield on the clay soil at the NEREC in 2012 and 2013 when 120 lb N/acre and 116 lb N/acre, respectively, were applied preflood. LaKast had maximum grain yields of over 200 bu/acre on the silt loam soil at the PTRS in all 3 years of study

(Norman et al., 2013; 2014; Table 5). Maximum grain yields of LaKast over the 3 years were achieved at the PTRS when 120 to 180 lb N/acre was applied preflood. However, yields of LaKast did not significantly increase at PTRS when more than 120 lb N/acre was applied preflood in any year. LaKast achieved 95% of the maximum yield at the PTRS in 2012, 2013, and 2014 when 100, 111, and 122 lb N/acre, respectively, were applied preflood (Fig. 4). Over the last 3 years maximum grain yields of over 200 bu/acre were achieved by LaKast on the silt loam soil at RREC when 120 lb N/acre was applied preflood, although grain yields never significantly increased when more than 90 lb N/acre was applied at the RREC in any year (Norman et al., 2013; 2014; Table 5). LaKast achieved 95% of the maximum yield at the RREC in 2012, 2013, and 2014 when 65, 82, and 85 N/acre, respectively, were applied preflood (Fig. 4). After 3 years of study it appears LaKast should do well with minimal lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on clay soils.

Grain yields of Mermentau at NEREC in 2014 were skewed due to the severe lodging and thus they will not be used in determining the proper N fertilizer rate for this variety (Table 6; Fig. 5). The N rate studies of Mermentau on the clay soil at NEREC in 2012 and 2013 (Norman et al., 2013; 2014; Fig. 5) reported maximum yields of 224 bu/acre when 210 lb N/acre was applied preflood and 189 bu/acre when 150 lb N/acre was applied preflood, respectively. Yields of Mermentau at the NEREC in 2012 were >200 bu/acre when 120 lb N/acre or more was applied; and in 2013, yields of Mermentau did not significantly increase when more than 150 lb N/acre was applied and remained quite stable when up to 210 lb N/acre was applied preflood. Mermentau achieved 95% of the maximum yield on the clay soil at the NEREC in 2012 and 2013 when 145 and 110 lb N/acre, respectively, were applied preflood. Maximum grain yields of Mermentau over the last 3 years were achieved at the PTRS when 120 to 180 lb N/acre was applied preflood (Norman et al., 2013; 2014; Table 6). However, yields of Mermentau did not significantly increase at PTRS when more than 120 lb N/acre was applied preflood in any year. Mermentau achieved 95% of the maximum yield at the PTRS in 2012, 2013, and 2014 when 94, 88, and 110 lb N/acre, respectively, were applied preflood (Fig. 5). Maximum grain yields of Mermentau on the silt loam soil at RREC were >200 bu/acre in 2012 and 2013 and 192 bu/acre in 2014 (Norman et al., 2013; 2014; Table 6). Mermentau did not significantly increase in yield at the RREC when >90 lb N/acre was applied preflood in any year. Mermentau achieved 95% of the maximum yield at the RREC in 2012, 2013, and 2014 when 70, 74, and 76 lb N/acre, respectively, were applied preflood (Fig 5). Grain yields of Mermentau over the last 3 years were relatively stable when the N rate to achieve maximum yield was exceeded by 30 to 60 lb N/acre. After 3 years of study, it appears Mermentau should yield well with minimum lodging when 135 to 150 lb N/acre is applied in a two-way split of 90 to 105 lb N/acre preflood and 45 lb N/acre at midseason when grown on silt loam soils, and 165 to 180 lb N/acre in a two-way split of 120 to 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on clay soils.

The Wells rice variety was included in the study as a control and to give a frame of reference for comparing the grain yield performance and lodging percentage of the new varieties over the N fertilizer rates applied at the three locations (Norman et al., 2013; 2014;Table 7; Fig. 6).

SIGNIFICANCE OF FINDINGS

The variety × N fertilizer rate study examines the grain yield performance of a new rice variety across a range of N fertilizer rates on representative soils and under climatic conditions that exist in the Arkansas rice-growing region. Thus, this study is able to estimate the proper N fertilizer rate for a variety to achieve maximum grain yield when grown commercially in the Arkansas rice-growing region. The five varieties studied in 2014 were: CL163, CL172, CL271, LaKast, and Mermentau. The data generated from multiple years of testing of each variety will be used to determine the proper N fertilizer rate to achieve maximum yield when grown commercially on most silt loam and clay soils in Arkansas.

ACKNOWLEDGMENTS

This research was supported primarily by the Arkansas Rice Research and Promotion Board through grower check-off funds and supported in part by Horizon Ag and support from both is greatly appreciated.

LITERATURE CITED

Norman, R.J., T.L. Roberts, C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Frizzell, J.D. Branson, and M.W. Duren. 2013. Grain yield response of ten new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:237-251. Fayetteville, Ark.

Norman, R.J., T.L. Roberts, C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Frizzell, J.D. Branson, and M.W. Duren. 2014. Grain yield response of eight new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:293-302. Fayetteville, Ark.

Table 1. Pertinent agronomic information for the Northeast Research and Extension Center (NEREC), Keiser, Ark., the Pine Tree Research Station (PTRS), near Colt, Ark., and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., during 2014.

Practices	NEREC	PTRS	RREC
Preplant fertilizers	---------	--------	90 lb P_2O_5/acre, 90 lb K_2O/acre + 10 lb Zn/acre
Planting date	7 May	6 May	5 May
Emergence date	18 May	17 May	16 May
Herbicide spray date	7 May	23 May	22 May
and procedures	1.5 pt Command/acre + 40 oz Facet L/acre + 1 oz Permit/acre	12.8 oz Command/acre	20 oz Obey/acre + 4 qt Riceshot/acre
Herbicide spray date	16 June	5 June	16 June
and procedures	4 qt Propanil/acre + 0.5 pt Granstand/acre	8 oz Broadband/acre + 1% COC	24 oz RiceStar/acre + 24 oz Facet L/acre + 0.75 oz Permit Plus/acre
Preflood-N date	19 June	17 June	16 June
Flood date	20 June	19 June	17 June
Harvest date	9 October	23 September	16 September

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL163 rice at three locations during 2014.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	20 [81b]	99	110
60	----	167	160
90	109 [98]	186	176
120	132 [98]	197	180
150	144 [98]	193	186
180	128 [98]	190	170
210	128 [98]	----	-----
$LSD_{0.05}$[c]	24.5	6.6	8.0

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.
[b] Numbers in superscript to the side of the yield are lodging percentages.
[c] LSD = least significant difference.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL172 rice at three locations during 2014.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------	(bu/acre)	----------
0	42 [33b]	95	137
60	----	147	183
90	111	173	190
120	136	187	194
150	147 [3]	192	188
180	144 [10]	194	182
210	147 [23]	----	-----
$LSD_{0.05}$[c]	10.6	6.4	10.4

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.
[b] Numbers in superscript to the side of the yield are lodging percentages.
[c] LSD = least significant difference.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL271 rice at three locations during 2014.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	--------	(bu/acre)	--------
0	60 [5b]	86	100
60	----	159	167
90	140 [69]	184	186
120	159 [92]	203	194
150	166 [93]	208	196
180	171 [97]	209	184
210	158 [97]	----	-----
$LSD_{0.05}$[c]	20.1	7.5	10.5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.

[b] Numbers in superscript to the side of the yield are lodging percentages.

[c] LSD = least significant difference.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of LaKast rice at three locations during 2014.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	--------	(bu/acre)	--------
0	33 [58b]	93	139
60	----	172	193
90	89 [94]	199	208
120	107 [97]	222	218
150	130 [95]	226	209
180	142 [98]	230	199
210	129 [98]	----	-----
$LSD_{0.05}$[c]	21.7	8.0	11.3

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.

[b] Numbers in superscript to the side of the yield are lodging percentages.

[c] LSD = least significant difference.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Mermentau rice at three locations during 2014.

N fertilizer rate	Grain yield		
	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	34 [73b]	89	134
60	----	154	175
90	115 [66]	179	188
120	129 [87]	198	192
150	129 [90]	200	192
180	145 [94]	199	186
210	117 [93]	----	-----
$LSD_{0.05}$[c]	23.4	10.3	14.4

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.

[b] Numbers in superscript to the side of the yield are lodging percentages.

[c] LSD = least significant difference.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Wells rice at three locations during 2014.

N fertilizer rate	Grain yield		
	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	35 [8b]	73	68
60	----	144	141
90	91 [18]	163	171
120	102 [18]	182	188
150	126 [54]	183	189
180	136 [84]	189	187
210	136 [89]	----	-----
$LSD_{0.05}$[c]	16.7	4.6	8.1

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, near Colt, Ark.; RREC = Rice Research and Extension Center, near Stuttgart, Ark.

[b] Numbers in superscript to the side of the yield are lodging percentages.

[c] LSD = least significant difference.

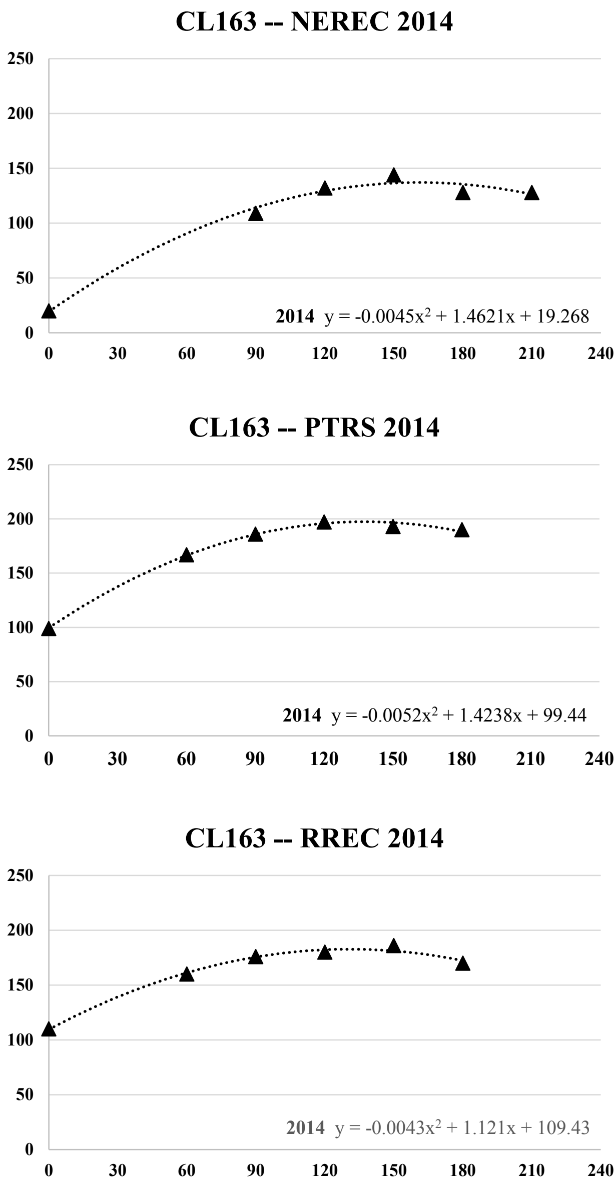


Fig. 1. Influence of N application rate on grain yield of Clearfield CL163 rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2014.

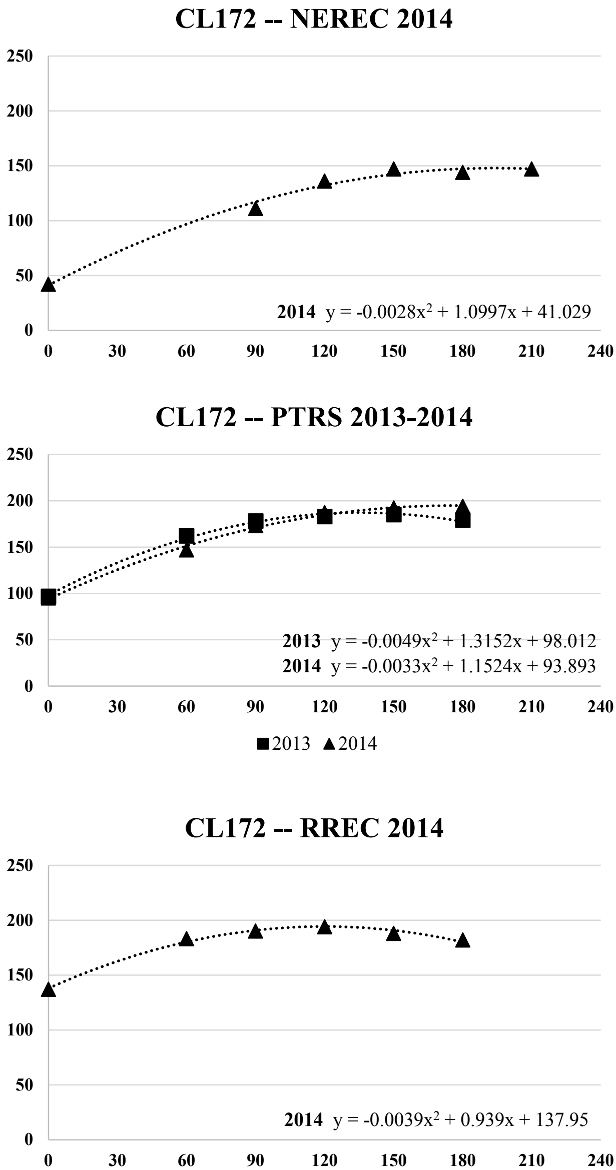


Fig. 2. Influence of N application rate on grain yield of Clearfield CL172 rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2014 and also 2013 at the PTRS.

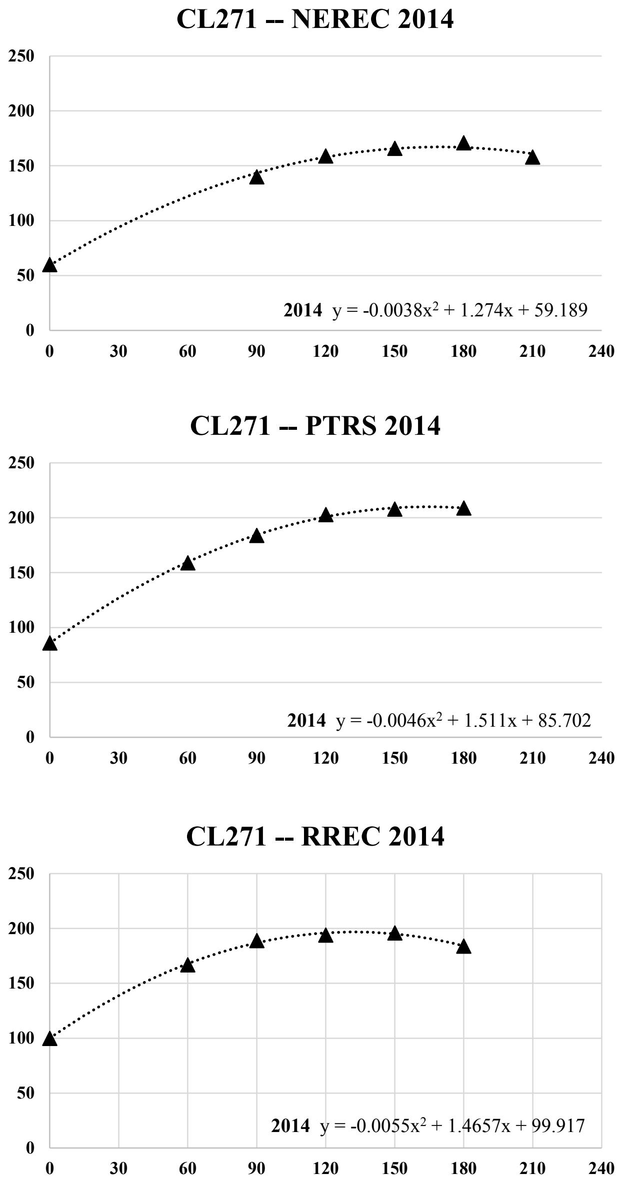


Fig. 3. Influence of N application rate on grain yield of Clearfield CL271 rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2014.

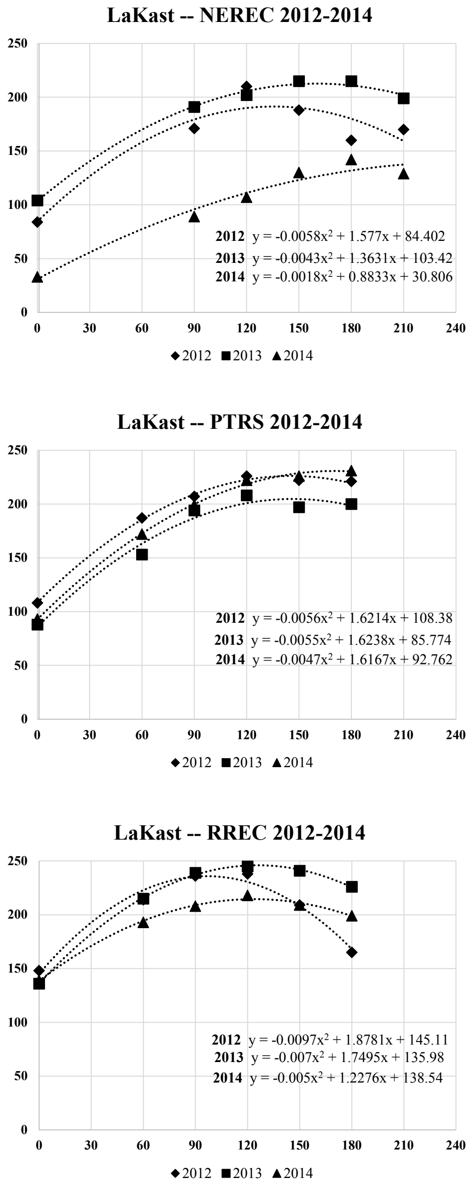


Fig. 4. Influence of N application rate on grain yield of LaKast rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2012-2014.

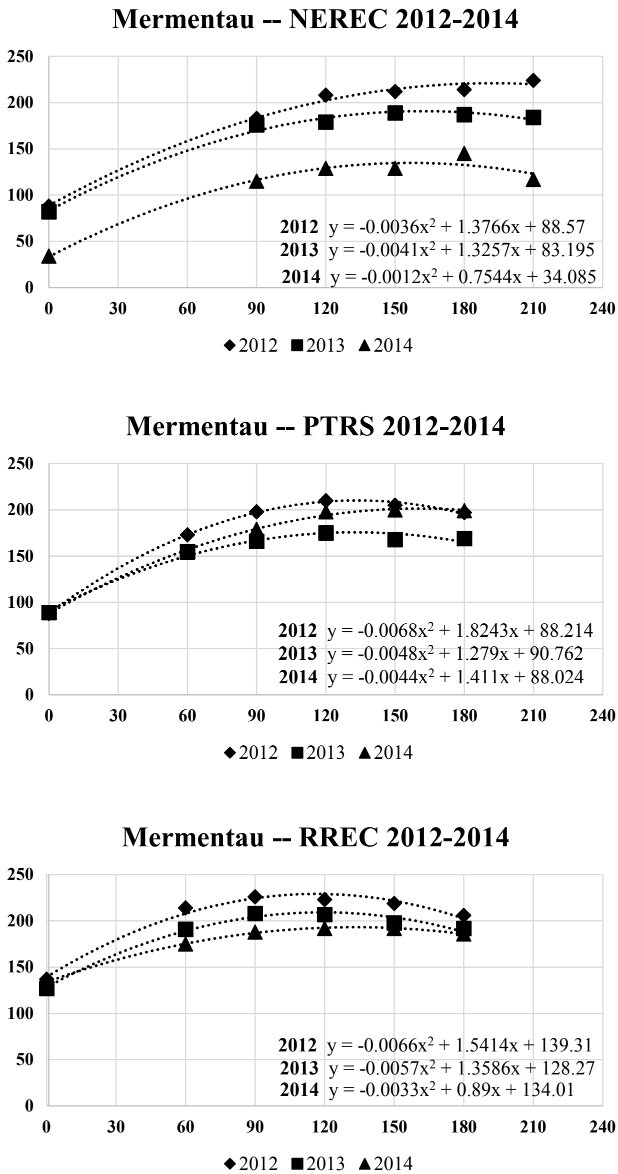
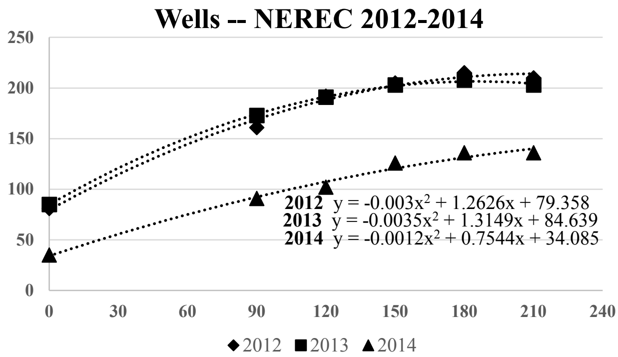
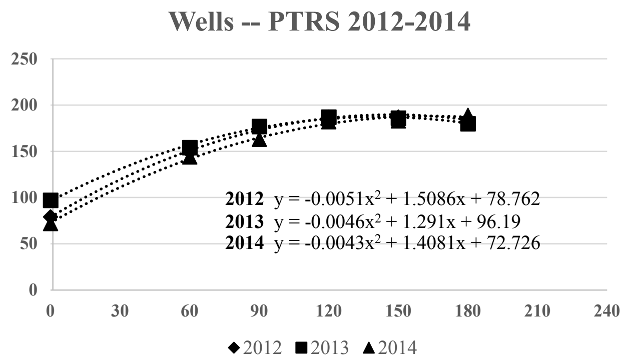


Fig. 5. Influence of N application rate on grain yield of Mermentau rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2012-2014.





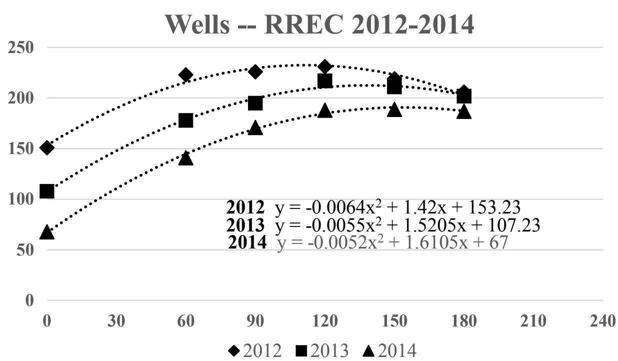


Fig. 6. Influence of N application rate on grain yield of Wells rice at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2012-2014.

Rice Grain Yield as Influenced by Various Water Management Practices

T.L. Roberts, J.T. Hardke, N.A. Slaton, C.E. Greub, J.T. Davidson, A.M. Fulford, S.M. Williamson, C.L. Scott, D.L. Frizzell, and E. Castaneda-Gonzalez

ABSTRACT

Increasing concerns over the water use associated with rice production in the Delta has led producers to consider alternative water management practices in an effort to preserve water resources and lower input costs. This trial was initiated to determine the influence of cultivar and water management strategy on rice grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Water management treatments included a conventional flood (CF), fields drained according to recommendations from the Degree-Day 50 (DD50) computer program, intermittent flood (IF), and flush (FL) irrigation treatments. The cultivars were chosen to represent commonly produced cultivars in the Delta region and included Presidio, CL151, Jupiter, Cheniere, Clearfield (CL) XL729, and CLXL745. A simple one-way analysis of variance (ANOVA) was used to compare cultivars within a water management treatment as well as how a cultivar performed across the various water management treatments. The two Rice Tec hybrids (CLXL729 and CLXL745), CL151, and Jupiter were among the highest-yielding cultivars across all water management treatments. However, Presidio was the lowest-yielding cultivar in all of the water treatments. The highest yield obtained in this trial was for the hybrid CLXL745 at 251 bu/acre and was achieved in both the CF and IF water management treatments. The lowest overall yield in the trial was Presidio in the FL treatment which only yielded 164 bu/acre. Data presented in this paper indicates that cultivar is an important consideration when implementing alternative water management practices as there is a significant influence on rice grain yield.

INTRODUCTION

Water management and availability is becoming an increasingly important issue for rice farmers in the Delta region of Arkansas. A recent report by the Arkansas Natural Resource Commission indicated that current groundwater supplies in the alluvial aquifer, where most of the groundwater used for agricultural production in Arkansas is obtained, is only 59% sustainable (Arkansas Natural Resources Commission, 2012). Knowing that the quantity of groundwater currently available is not sustainable at current usage rates, the desire to look at alternative water management strategies for rice production is coming to the forefront. Direct-seeded, delayed-flood production practices are the most commonly used technique in Arkansas and it is estimated that ~99% of the acreage is produced using a conventional flood irrigation practice (Hardke, 2014). Currently less than 1% of the total rice acreage in Arkansas is produced with alternative irrigation practices including furrow or sprinkler irrigation. In addition to the flood practices currently used, it is estimated that roughly 78% of the land devoted to rice production in Arkansas relies on groundwater for the primary irrigation water source (Hardke, 2014). Irrigation costs represent a significant portion of the input costs associated with rice production and rank second only behind fertilization (Flanders et al., 2014). Increasing concern associated with the unsustainable use of groundwater for rice production, coupled with the relatively high cost of irrigation, has placed more emphasis on researching alternative irrigation strategies that reduce water use.

Previous research conducted in Arkansas focused on the influence of alternative water management practices on rice grain yield and greenhouse gas emissions (Anders et al., 2013). This research indicated that rice can maintain relatively high grain yields with alternative water management practices, but was limited in scope as it only included hybrid rice cultivars. In order to assess the viability of these alternative water management practices and help producers make informed decisions concerning cultivar selection, more work needs to be done. Therefore this research was established to look at the influence of cultivar and water management practice on rice grain yield.

METHODS AND MATERIALS

Field experiments were established at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on 24 April 2014. Six commonly produced cultivars were chosen for this trial to represent planting practices across the Mid-south. Pure-line varieties were planted at a seeding rate of ~68 lb seed/acre and hybrids were planted at ~27 lb seed/acre. Emergence date for this trial was 10 May 2014 and the plots were flooded on 6 June 2014. Prior to flooding, 120 lb N/acre was applied as a single preflood application and the water management treatments were established within 48 h following urea fertilizer application. The water management treatments implemented included a conventional flood (CF), DD50 drain (DD50), intermittent flood (IF), and flush (FL) irrigation treatments. In the CF treatment, water was maintained throughout the season at a 3- to 4-inch level following best management practices for direct-seeded, delayed-flood rice production.

Water management in the DD50 treatment was similar to the CF except that the flood was drained until the soil cracked based on the median DD50 straighthead drain date provided for each cultivar. The IF treatment involved the establishment of a 3- to 4-inch flood that was allowed to drop until soil moisture sensors indicated the need to reapply water at which time another 3- to 4-inch flood was applied. Similar to the IF treatment, the FL treatment was flushed (water applied for several hours and then drained off) when soil moisture level dropped to a predetermined level. Soil moisture sensors were installed prior to flooding and used to initiate irrigation in the IF and FL treatments when the soil moisture level dropped to ~-20 centibars. The soil moisture level selected to trigger water application in the IF and FL treatments was such that the soil remained moist and the rice plants should not have experienced drought conditions. During this trial the DD50 bay was drained on 24 June 2014 and reflooded on 1 July 2014. The IF treatment received water to reestablish a flood on 7 July 2014 and 28 July 2014, and flushed on 2 September 2014 prior to draining. The FL irrigation treatment received irrigation 20 times throughout the course of the season and the application dates were as follows: 6 June, 20 June, 23 June, 27 June, 1 July, 3 July, 7 July, 9 July, 11 July, 14 July, 21 July, 25 July, 28 July, 4 August, 8 August, 11 August, 15 August, 10 August, 22 August, and 2 September.

Following maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bu/acre at 12% moisture. A bushel of rice weighs 45 pounds (lb). During harvest, the FL irrigation treatment was harvested with a different combine, but all yield values were similar. A simple one-way analysis of variance was used to compare cultivars within a water management treatment as well as a single cultivar across water management treatments, and means were separated using Fishers protected least significant difference test at $P = 0.05$ level. All statistical analyses were carried out using JMP 11.0 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Rice grain yields were significantly influenced by cultivar and water management strategy. Therefore, for the purposes of this paper a discussion of rice grain yields within each water management practice will be presented. The CF treatment is the current standard by which all other practices will be compared. A direct-seeded, delayed-flood production system has some of the highest nitrogen use efficiencies in the world and is very efficient in terms of rice produced per unit area of land. In this trial within the CF irrigation management treatments, the highest numerical yields were seen for Presidio, Cheniere, CLXL745, and CLXL729, with yields of 181, 211, 249, and 251 bu/acre, respectively (Table 1). Although the yields of Jupiter and CL151 in the CF treatment were not the highest numerical yields, they were not statistically different than the highest yielding water management treatments for these two cultivars. Overall the yields for all cultivars within the CF treatment were exceptional.

The DD50 drain treatment is designed to mimic a traditional drain that would be conducted based on the DD50 program to reduce the potential of straighthead for susceptible cultivars. Although a continuous flood is maintained for the majority of the growing season, there is still a 7 to 10 day period where no water is being pumped on the field, which can reduce total water usage and pumping costs. In theory, there should be no yield loss associated with a DD50 drain when properly executed. However in this trial, Presidio had a significant yield loss when this treatment was compared to the CF treatment, suggesting that Presidio is not as drought tolerant as the other cultivars used in this trial. Presidio was the only cultivar that exhibited a significant yield loss in the DD50 treatment compared to the CF; and for all other cultivars, the yield difference between these two treatments was <7 bu/acre.

Intermittent flooding is a way for producers to reduce total water usage and pumping costs, but lower the risk associated with something like flush-, furrow-, or sprinkler-irrigated rice. When IF is implemented, the water is pumped to a 3- to 4-inch depth and allowed to evapotranspirate or soak in until the soil moisture level requires more irrigation to prevent yield loss. The IF treatment in this trial would dry to the point that you could walk on the soil and leave footprints, but never really track mud. For all cultivars used in this trial, the IF yields were not statistically different than those obtained using the CF irrigation practice. The highest numerical yields for Jupiter, CL151 and CLXL745 were all obtained within the IF treatment. Although high yields were achieved with the IF irrigation treatment, it should be pointed out that blast was not noted in any of the plots, which could have severely limited yields if it had been present. Intermittent flooding can be a viable alternative to CF irrigation when diseases such as rice blast are not present.

Flush or furrow-irrigated rice has the greatest potential for water savings and can significantly increase water use efficiency of rice. In this trial, the FL treatment produced the statistically lowest yields of all the irrigation treatments. Yield losses using the FL treatment ranged from 16% for CL151 to 34% for CLXL745 when compared to the highest-yielding irrigation treatment for those respective cultivars. The yield reductions for hybrid rice seen here are similar to what was reported by Anders et al. (2013), but are counterintuitive to what one might expect. Traditionally we think of hybrids being more drought resistant, but in this particular trial they took more of a yield penalty in the FL irrigation treatment (on a percent yield reduction basis) than did the pure-line cultivars.

SIGNIFICANCE OF FINDINGS

The results presented here indicate that alternative water management practices can be implemented to reduce total water usage and input costs associated with irrigation while maintaining relatively high yield potentials. Although water usage was not recorded in this trial, IF has been shown to have lower total water use and in this trial there was no significant difference in rice yield for each cultivar when compared to CF irrigation practices. However during the 2014 growing season at RREC, rice blast was not present in this trial, which could have had a significant impact on rice yield in the IF and FL irrigation treatments where a permanent flood is not maintained throughout the growing season. Pure-line cultivars also performed well in the IF which indicates that they may be viable options in these alternative irrigation management practices.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board and the US Rice Foundation.

LITERATURE CITED

Anders, M., K Watkins, C. Henry, T. Siebenmorgen, and K Brye. 2013. The effect of growing rice with less water on grain yields, irrigation water efficiency, and greenhouse gas emissions. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:174-181. Fayetteville, Ark.

Arkansas Natural Resources Commission. 2012. Arkansas ground-water protection and management report for 2011. Arkansas Natural Resources Commission. 101 East Capitol, Suite 350. Little Rock, Ark.

Flanders, A., R. Baker, T. Barber, T. Faske, H. Ginn, C. Grimes, J. Hardke, K. Lawson, G. Lorenz, R. Mazzanti, C. Norton, B. Robertson, and G. Studebaker. 2014 (Revised March 2015). 2015 Crop enterprise budgets for Arkansas field crops planted in 2015. University of Arkansas Division of Agriculture, Cooperative Extension Service, AG-1302, December 2014.

Hardke, J. 2014. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:13-23. Fayetteville, Ark.

Table 1. Influence of cultivar and water management on rice grain yield at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., during 2014.

	Water Management				
Cultivar	Flood	DD-50 Drain	Intermittent	Flush	$LSD_{0.05}$[a]
	-----Yield (bu/acre)-----				
Jupiter	233	236	243	204	14.6
Presidio	181	162	180	148	13.4
CL 151	220	221	221	186	10.0
Cheniere	211	205	204	164	8.2
RT CLXL729	249	246	246	173	12.7
RT CLXL745	251	244	251	165	15.6
$LSD_{0.05}$[b]	16.6	12.5	13.6	14.7	

[a] $LSD_{0.05}$ to compare cultivars across water management treatments.
[b] $LSD_{0.05}$ to compare cultivars within a water management treatment.

The Effect of Delaying Preflood-Nitrogen Fertilization on Grain Yield of Flood-Irrigated Rice

N.A. Slaton, T.L. Roberts, J. Hardke, R.J. Norman,
R.E. DeLong, R. Dempsey, M. Fryer, R. Parvej, and J. Hedge

ABSTRACT

Preflood application of urea-nitrogen (N) to a dry soil is challenging in some years due to frequent rainfall during late May and early June. Our objective was to evaluate how delaying the preflood, urea-N application on a very-short-season cultivar influenced grain yield response to N rate. Clearfield 111 rice was fertilized with a single, preflood application of 0, 40, 80, 120, and 160 lb urea-N/acre on four different dates (4 June, 12 June, 18 June, and 27 June). Rice grain yield for the 4, 18, and 27 June fertilization dates increased quadratically as N rate increased and the 12 June fertilization date yield response was positive and linear. The results suggest that the preflood urea-N can be delayed for several weeks without reducing grain yield assuming that urea-N losses were similar among N application times. The results are tenuous because the conditions under which urea-N was applied differed and may have led to different amounts of N loss.

INTRODUCTION

Rice (*Oryza sativa* L) uptake of preflood-applied, urea-N fertilizer is very efficient when done properly. Proper application includes the use of an effective urease inhibitor, application to a dry soil, and rapid incorporation by flooding. Unfortunately, in some years, application of the preflood urea-N to a dry soil is challenging due to frequent rainfall during late May and early June. This was the situation that occurred in 2014. Weather records for 25 May to 12 June show 8 (of 19) days of measurable rainfall totaling 5.4 inches at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and 10 days of rainfall totaling 7.9 inches at the Rohwer Research Station. Currently, the recommendation is to wait a reasonable amount of time for the soil to dry before applying preflood N. However when a dry soil for urea-N application cannot be achieved, growers are encouraged to apply the urease inhibitor-treated urea to the moist soil surface and if possible allow the soil to dry for 2 days before flooding. Ammonia loss from the urea during the 2-day drying time is delayed by the urease inhibitor and the drying allows urea to be incorporated below the soil surface when the flood is applied. The DD50 guideline for the absolute deadline for applying the preflood N was established in the early 1990s with longer season cultivars and needs to be reevaluated since the duration of the vegetative growth stage of many existing cultivars and hybrids has been reduced. Our objective was to evaluate how delaying the preflood, urea-N application on a very-short-season cultivar influenced grain yield response to N rate.

PROCEDURES

The experiment was conducted at the PTRS on a Calhoun silt loam that was previously seeded to soybean and fallowed in 2013 due to a stand failure. The N-STaR value of 6, 18-inch deep composite soil samples for the field averaged 70 ppm (standard deviation = 10 ppm) and recommended an N rate of 160 lb N/acre. Composite 4-inch deep soil samples showed soil chemical property means of 7.8 pH, 35 ppm P (Mehlich-3), and 80 ppm K (Mehlich-3). A blanket application of 80 lb K_2O/acre was applied after rice emergence.

Rice (CruiserMaxx-treated CL111) was seeded (90 lb/acre) on 23 April in four adjacent areas that were each separated by a levee to represent four different N fertilization and flood times of rice that was planted on the same date. Individual plots consisted of 9, 16-ft long rows spaced 7.5 inches apart and were surrounded by a 2.5-ft wide plant-free alley. Rice was fertilized preflood with single applications of 0, 40, 80, 120, and 160 lb urea-N/acre on four different dates (4 June, 12 June, 18 June, and 27 June). Note that the first N application date was delayed by one week waiting for dry soil conditions. All urea-N fertilizer was treated with the labeled rate of a urease inhibitor (3 qt Agrotain Ultra/ton urea, 26.7% a.i.). At maturity, 8 of the 9 rows in each plot were harvested with a plot combine, grain moisture and weight was recorded, and rice grain moisture was adjusted to 12% for final yield calculations.

Each trial (N application time) contained five N rates arranged as a randomized complete block design and four blocks. Regression analysis was performed using replicate data with the MIXED procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) using a model that contained the intercept term (N application time) and the linear and quadratic terms of N rate. The full model was run, the most complex non-significant ($P > 0.15$) term was deleted (if needed), and the simplified model was run again until the simplest final model with significant terms was derived. Predicted yield comparisons among N application times were made using the LSMEANS statement at preflood-N rates of 0, 120, and 160 lb urea-N/acre with differences interpreted as significant at the 95% level.

RESULTS AND DISCUSSION

Rice grain yield for the 4, 18, and 27 June fertilization dates increased quadratically as N rate increased and the rice yield response for the 12 June fertilization date was positive and linear (Table 1 and Fig. 1). For the three N fertilization dates that produced a quadratic relationship, the preflood-N rate predicted to produce maximal yield for CL111 was 173 lb urea-N/acre for 4 June, 150 lb urea-N/acre for 18 June, and 177 lb urea-N/acre for 27 June. The predicted yields within each of the examined N rates (120 and 160 lb urea-N/acre) were similar among the three dates showing quadratic relationships and greater than the predicted yield from the 12 June urea-N application date. Grain yield of rice receiving no-N fertilizer increased numerically and sometimes significantly as the permanent flood was delayed and followed the statistical order of: 4 June < 12 June = 18 June < 27 June (Table 1).

The soil moisture and weather conditions in which the urea-N was applied varied somewhat among the four application dates. For the N applications on 4 and 12 June, the soil was moist from rains that had occurred 2 days before the N was applied (0.33 inches on 2 June and 2.5 inches on 8 to 10 June). The plots were flooded 2 days following the urea-N application. Rain (0.37 inch) also occurred on 12 June after the urea-N was applied. The 18 and 27 June N applications were applied to dry soil. Thus, the N applications on 4 and 12 June were made under less than ideal situations which may have led to some N loss and thus some yield loss. Based on the yield results, a substantial amount of urea-N was lost from the 12 June application. Rice heading was delayed by delaying the preflood-N rate. Rice that was fertilized with 160 lb N/acre on 4 and 12 June reached 100% heading within 2 days of each other, which was 7 to 11 days earlier than 100% heading of rice fertilized on 18 and 27 June, respectively.

SIGNIFICANCE OF FINDINGS

The results from research with CL111 in 2014 suggest that the preflood N can be delayed for several weeks without reducing grain yield assuming that urea-N losses were similar among N application times. The results are tenuous because the conditions under which urea-N was applied differed and may have led to different amounts of N loss. Additional research is warranted to confirm that these results are consistent across soils under uniform (e.g., dry) soil conditions and rice genotypes.

ACKNOWLEDGMENTS

Research was funded by a grant from the Rice Check-off Program administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

Table 1. Regression coefficients and *P*-values for grain yield of CL111 rice planted on the same day and fertilized with preflood urea-N on four different dates during 2014 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station.

	Regression coefficients[a] (SE[b])		
Preflood-N date	Intercept[c]	Linear	Quadratic
4 June	69 (±5) c	1.415 (±0.134)	-0.00409 (±0.00080)
12 June	84 (±5) b	0.545 (±0.134)	0.00023 (±0.00080)[d]
18 June	88 (±5) b	1.383 (±0.134)	-0.00461 (±0.00080)
27 June	103 (±5) a	1.004 (±0.134)	-0.00283 (±0.00080)

[a] Coefficients for the equation y = a + bx + cx^2 where y = grain yield (bu/acre); a = intercept; b = linear coefficient; c = quadratic coefficient; and x = preflood-N rate (lb urea-N/acre.

[b] SE = standard error. All coefficients are significantly (P <0.05) different than zero, unless noted.

[c] Intercept values followed by different lowercase letters indicate statistical differences among values for rice receiving no N fertilizer.

[d] Coefficient not different than zero.

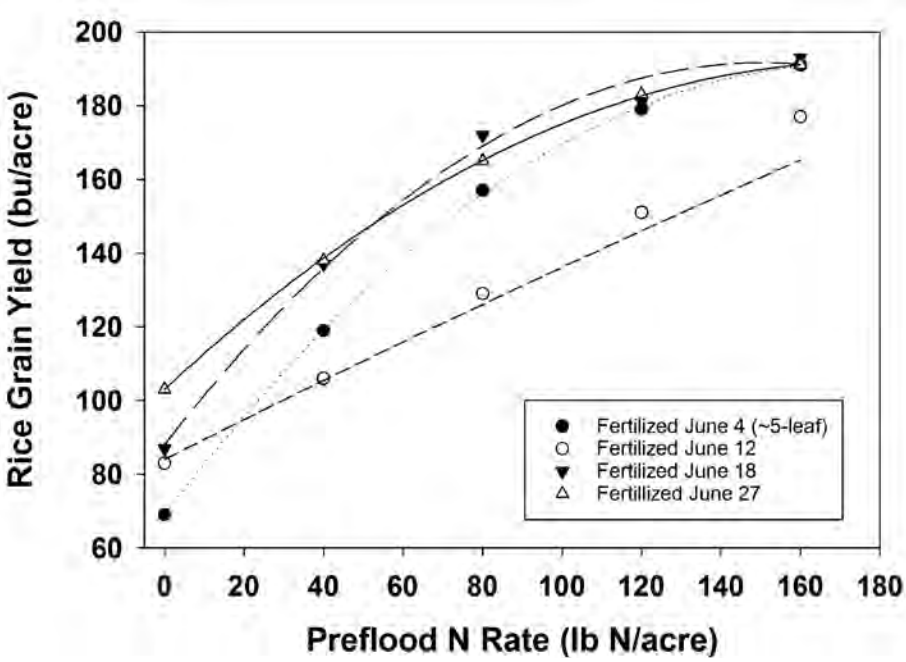


Fig. 1. Grain yield response to preflood urea-N rate at four different N application dates for CL111 rice that was seeded on the same date in a trial conducted during 2014 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station. Regression coefficients are listed in Table 1.

Rice and Soybean Response to Short- and Long-Term Phosphorus and Potassium Fertilization Rate

N.A. Slaton, T.L. Roberts, R.J. Norman, J.T. Hardke, R.E. DeLong, J. Hedge, and S.D. Clark

ABSTRACT

Knowledge of soil and crop yield response to long-term fertilization practices is important for sustainable soil nutrient and crop management. Our research objectives were to evaluate long-term rice (*Oryza sativa* L.) and soybean [*Glycine max* (L.) Merr.] yield and soil-test phosphorus (P) and potassium (K) responses across time to P-and K-fertilization rates on silt-loam soils. This report summarizes 2014 crop and soil-test information from six long-term field trials cropped to a rice-soybean rotation at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS, Calhoun silt loam) and Rice Research and Extension Center (RREC, Dewitt silt loam). Results show that soil-test K is increased by 1 ppm from application of 35 to 37 lb K_2O/acre on a Calhoun silt loam and 6 to 11 lb K_2O/acre on a Dewitt silt loam. Soil-test P increases by 1 ppm for every 14 lb P_2O_5/acre applied. Rice and soybean incur moderate to large yield losses when low rates or no K fertilizer is applied to silt loam soils. Rice and soybean yields appear to be less dependent on P fertilization.

INTRODUCTION

The process of developing soil-test-based fertilizer recommendations for crop production contains multiple steps including correlation of soil test, calibration of fertilizer rates or selecting a fertilization philosophy, and validating the accuracy of the recommendations. The correlation and calibration components require years of research across numerous sites that represent a range of soil nutrient availability index values, soils, variety, and environmental conditions. The use of long-term fertilizer rate plots is important to this process because over time soils with a range of nutrient availability index values are created and allows researchers to document the rate at which soil nutrients are depleted or accumulated. Such knowledge is useful in selecting the proper time interval for building soil nutrient concentrations for the build and maintain (or build the soil) philosophy.

Arkansas soils used for rice and soybean production tend to have lower soil-test P and K values than soils used for the production of other crops, but the median value of these soils tends to be slightly above the critical concentration (DeLong et al., 2013). Among the greatest challenges for developing fertilizer recommendations is finding soils that respond positively to fertilization. Soils that produce a range of nutrient deficiencies are sometimes difficult to find. In Arkansas, finding undisturbed soils where rice and soybean respond positively to P fertilization has been especially difficult. The long-term plot approach should aid our understanding of soil-P availability and eventually create P-deficient soils that will facilitate research, development of more specific recommendations, and aid farmer and agent training. Our research goals are to evaluate: i) long-term rice and soybean growth and yield and ii) soil-test P and K responses across time to P- and K-fertilization rates on silt loam soils. This report summarizes our objective of monitoring these responses in long-term fertilization trials during the 2014 growing season.

PROCEDURES

Long-term field trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rice Research and Extension Center (RREC) were continued in 2014. The two PTRS K trials were established in either 2000 (cropped to rice in 2014, PTRS-Kr) and 2002 (cropped to soybean in 2014, PTRS-Ks) on a Calhoun silt loam. The RREC trials were established in 2007 on a Dewitt silt loam. The research areas have been cropped to a 1:1 rice-soybean rotation and managed with no-tillage. The same (or similar) P or K fertilizer treatments have been applied to each plot since the trials were initiated. Composite soil samples (0- to 4-inch depth) were collected from each plot in mid to late winter of 2014. Soil samples were oven-dried (55 °C), crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture, extracted using the Mehlich-3 method, and elemental concentrations were determined by inductively coupled plasma emission spectroscopy. Selected soil chemical property means for each of the six experiments are listed in Table 1. Triple superphosphate was broadcast to K trials before planting to provide 50 to 60 lb P_2O_5/acre and ~90 lb K_2O/acre was broadcast as muriate of potash to the P-rate trials at the RREC. Soil-test and crop-yield results have been summarized and reported in previous years (Slaton et al., 2011a, b; 2014).

Potassium-fertilizer rate trials are conducted at both sites with common rates of 0, 40, 80, 120, and 160 lb K_2O/acre/year applied as muriate of potash. The influence of P-fertilizer rate is evaluated only at the RREC and includes 0, 40, 80, 120, and 160 lb P_2O_5/acre/year applied as triple superphosphate. Fertilizer treatments were applied shortly before planting at each site.

At the RREC, plots were 15-ft wide and 25-ft long and each plot contained 24 rows of rice. The rice cultivar CL152 (treated with 7 oz CruiserMaxx/cwt) was drill-seeded (90 lb/acre) into the previous year's soybean residue and Armor 47-R13 soybean was drill-seeded (70 lb/acre) into the previous year's rice stubble at the RREC on 24 April. Management of rice and soybean with respect to stand establishment, pest control, irrigation, and other practices closely followed University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for full-season soybean and direct-seeded, delayed-flood rice production.

At the PTRS, individual plots were 25- to 26-ft wide and 16-ft long with a 1- to 2.5-ft wide alley surrounding each plot. Each plot contained 36 rice rows spaced 7.5 inches apart or 20 soybean rows spaced 15 inches apart. Clearfield 111 rice was drill-seeded on 23 April. For soybean one-half of each plot was seeded with Armor 48-R66 and the other half with Armor 55-R22. Whole plant samples were collected from rice trials at the early heading stage in all K trials and trifoliate leaves were collected at the R2 stage in soybean trials. At maturity, plots were trimmed, length was measured, and the middle rows were harvested with a small-plot combine. Grain weights and moistures were determined by hand and used to adjust grain yields to 12% (rice) or 13% (soybean) moisture by weight for statistical analysis.

Each experiment was a randomized complete block (RCB) design. Each trial contained 6 (all RREC trials), 8 (PTRS-Kr), or 9 (PTRS-Ks) blocks. Analysis of variance was performed by trial with the MIXED procedure in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with significant differences interpreted when $P < 0.10$. The PTRS-Ks trial was a split plot where annual K rate was the main plot and soybean cultivar was the subplot. Mean separations were performed by Fisher's protected least significant difference test. Damage from deer browsing occurred in several PTRS-Ks plots which were omitted from the analysis of variance. After removal of the compromised plots each treatment was represented in at least five blocks.

RESULTS AND DISCUSSION

Long-term fertilization has resulted in significant Mehlich-3 extractable P and K differences among the annual fertilizer rates (Tables 2 and 3). At the PTRS, despite relatively high rates of K fertilization, the minimum and maximum soil-test K values differ by only 50 ppm with the soil-test K in the 160 lb K_2O/acre/yr rate considered Medium (91 to 130 ppm K). Based on the cumulative amount of K applied, 36 to 37 lb K_2O/acre is needed to increase soil-test K (0- to 4-inch depth) of the Calhoun silt loam by 1 ppm (Table 2). In contrast, the Dewitt silt loam (RREC-Kr and RREC-Ks) requires 6 to 11 lb K_2O/acre to increase soil-test K by 1 ppm. Although the RREC trials were established more recently than the PTRS trials, the difference between the maximum and minimum soil-test K is much greater (78 to 135 ppm K). Reasons for the differences in soil-test K responses between the RREC-Kr and -Ks trials are not clear, but could be due to the crop rotation sequence. Soil-test P at the RREC-Pr and -Ps trials ranges from what is currently categorized as Very Low (0 to 15 ppm) to Above Optimum (>50 ppm, Table 3). Application of 14 lb P_2O_5/acre is required to increase soil-test P by 1 ppm for the Dewitt silt loam. Although not statistically compared, soil-test P tended to be lower for each rate when samples were collected after rice.

Long-term omission of K fertilization on the Calhoun silt loam at PTRS has resulted in yield losses of 14% to 17% for soybean and 30% to 33% for rice compared to the annual K rates that optimize yields, which range from 80 to 160 lb K_2O/acre/yr (Table 4). Although application of 80 to 160 lb K_2O/acre/year did not produce significantly different yields, the highest numerical yields were produced with the greatest rates. Application of 40 lb K_2O/acre/yr resulted in yields greater than the no-K control but less than the optimal K rates. The established critical tissue K concentrations for whole rice plants at early heading (1.3%) and recently matured trifoliolate soybean leaves (91.5% to 1.8%) from the uppermost nodes are good indicators of the plants K nutritional status. The interaction between soybean cultivar and annual K rate was not significant for yield ($P = 0.4721$) or tissue K concentration ($P = 0.8244$). The main effect of soybean cultivar significantly affected leaf K concentration (P = 0.0.0001) but not yield ($P = 0.9463$). Averaged across annual K rates, Armor 48-R66 (maturity group IV, 1.43% K) contained lower tissue K than Armor 55-R22 (1.63% K).

Rice yield was not significantly affected by P fertilization (RREC-Pr, Table 5) despite the low soil-test P (Table 2). Rice yield was influenced by K fertilization (RREC-Kr) with the no-K control producing 7 to 10 bu/acre lower yields than rice fertilized with 40 to 160 lb K_2O/acre/yr (Table 5). The lower yields in the no-K plots indicate plant-available soil K is slowly being depleted by crop removal, which is supported by the plant K concentration differences.

Soybean leaf P concentration and grain yields at the RREC were affected by both P and K fertilization (Table 6). Soybean leaf P and K concentrations increased as annual P rate increased. Soybean fertilized with 40 to 80 lb P_2O_5/acre/yr produced yields statistically equal to the no-P control and greater than soybean fertilized with 120 to 160 lb P_2O_5/acre/yr. Annual application of 40 to 160 lb K_2O/acre/yr generally produced equal yields that were 5 to 10 bu/acre greater than soybean receiving no K.

SIGNIFICANCE OF FINDINGS

Long-term P and K fertilization trial results show: i) building soil-test K is more difficult in the Calhoun soil than the Dewitt soil, ii) soil-test P in the Dewitt soil can be increased with moderate to high P-fertilizer rates, iii) substantial rice and soybean yield loss occurs from long-term omission of K fertilizer, iv) application of very low annual K rates reduces yield loss but prevents production of maximal yield, and v) maximal rice yield can be produced on soils with Very Low Mehlich-3 extractable P with no P fertilization for a number of years. These long-term fertilization plots have produced valuable information for managing soil-test P and K, making crop fertilization decisions, and comparing soil-test methods.

ACKNOWLEDGMENTS

Research was funded by the Arkansas Rice and Soybean Check-off Programs with funds administered by the Arkansas Rice and Soybean Research and Promotion Boards and the University of Arkansas System Division of Agriculture.

LITERATURE CITED

DeLong, R.E., S.D. Carroll, N.A. Slaton, M. Mozaffari, and C. Herron. 2013. Soil test and fertilizer sales data: Summary for the 2011 growing season. *In:* N.A. Slaton (ed.). Wayne E. Sabbe Arkansas Soil Fertility Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 608:7-17. Fayetteville, Ark.

Slaton, N.A., R.E. DeLong, C.G. Massey, J. Shafer, S. Clark, and J. Branson. 2011a. Soybean yield response to phosphorus and potassium fertilization. *In:* N.A. Slaton (ed.). Wayne E. Sabbe Arkansas Soil Fertility Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 588:53-57. Fayetteville, Ark.

Slaton, N.A., R.J. Norman, T.L. Roberts, R.E. DeLong, C.G. Massey, and S. Clark. 2011b. Rice response to nitrogen and potassium fertilization rate. *In:* R.J. Norman and K.A.K. Moldenhauer (eds) B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:253-258. Fayetteville, Ark.

Slaton, N.A., T.L. Roberts, R.J. Norman, J. Hardke, R.E. DeLong, J.B. Shafer, C.G. Massey, and S.D. Clark. 2014. Rice and soybean response to short- and long-term phosphorus and potassium Fertilization Rate. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:332-338. Fayetteville, Ark.

Table 1. Selected soil chemical property means (0- to 4-inch depth, *n* = 6-9) of long-term plots used to evaluate rice and soybean response to P and K fertilization rate at the Pine Tree Research Station (PTRS) and Rice Research Extension Center from soil samples collected in late winter 2014.

Site[a]	Soil pH[b]	Mehlich-3 extractable soil nutrients					
		P	K	Ca	Mg	S	Zn
		--------(ppm)--------					
PTRS-Kr	7.9	33	NA[c]	2345	389	15	11.6
PTRS-Ks	7.7	27	NA[c]	2373	392	24	9.7
RREC-Kr	6.0	38	NA[d]	1124	152	5	6.1
RREC-Ks	5.5	32	NA[d]	850	98	7	9.8
RREC-Pr	5.6	NA[d]	128	1031	129	5	7.9
RREC-Ps	5.6	NA[d]	129	972	117	10	10.3

[a] Location abbreviations: The uppercase letter following the site abbreviation indicates potassium (K) or phosphorus (P) and the lowercase letter indicates crop (r, rice; and s, soybean).

[b] Soil pH measured in a 1:2 soil:water mixture

[c] Mean soil-test K values for each annual K rate in the long-term trials are listed in Table 2

[d] Mean soil-test P and K values for each annual P and K rate in the long-term trials are listed in Table 3.

Table 2. Soil-test K of a Calhoun silt loam cropped to rice (r) and soybean (s) as affected by annual K rate in the long-term K fertilization trials at the Pine Tree Research Station (PTRS) established in 2000 (PTRS-Kr) or 2002 (PTRS-Ks).

Annual K rate	PTRS-Kr	PTRS-Ks
(lb K_2O/acre/year)	------ (ppm K) ------	
0	43	69
40	52	76
80	67	79
120	84	91
160	93	121
$LSD_{0.10}$	8.2	17.6
P-value	<0.0001	0.0003
C.V., %	14.1	13.1
Slope[a]	0.027	0.028
R^2	0.77	0.65

[a] Regression analysis was performed on soil-test values from four replicate plots that had received annual K fertilization since 2000 or 2002 (note the annual rates were changed to the listed values after 2006). Soil-test K values were regressed across the cumulative lb K_2O/acre applied.

Table 3. Soil-test P and K of a Dewitt silt loam as affected by annual P and K rates in long-term trials established in 2007 and cropped to rice (r) and soybean (s) at the Rice Research Extension Center (RREC).

	Potassium trials		Phosphorus trials	
Annual rate	RREC-Kr[a]	RREC-Ks[b]	RREC-Pr[a]	RREC-Ps[b]
(lb P_2O_5 or K_2O/acre/year)	------------------(ppm)------------------			
0	80	99	14	9
40	103	124	25	20
80	129	139	41	36
120	181	152	53	50
160	215	177	72	66
$LSD_{0.10}$	16.6	12.9	6.1	5.5
P-value	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	11.8	9.4	14.9	15.1
Slope[c]	0.175	0.092	0.072	0.072
R^2	0.87	0.82	0.92	0.93

[a] Soil samples collected in late winter/spring 2014 following the 2013 soybean crop.
[b] Soil samples collected in late winter/spring 2014 following the 2013 rice crop.
[c] Regression of soil-test P values from 2014 soil samples after seven years of cropping and cumulative P and K fertilization (annual rate × 7). Dividing 1 by the slope (1/slope) gives the lb K_2O or P_2O_5 to increase soil-test K or P by 1 ppm.

Table 4. Rice (r) and soybean (s) tissue K concentrations and grain yields as affected by annual K rate for the in the long-term trials at the Pine Tree Research Station (PTRS).

	PTRS-Kr		PTRS-Ks	
Annual K rate	Plant K[a]	Yield	Leaf K[b]	Yield
(lb K_2O/acre/year)	(% K)	(bu/acre)	(% K)	(bu/acre)
0	0.63	137	1.14	49
40	0.88	181	1.45	55
80	1.17	196	1.65	57
120	1.48	202	1.69	59
160	1.67	204	1.72	58
$LSD_{0.10}$	0.11	11	0.12	3.8
P-value	<0.0001	<0.0001	<0.0001	0.0004
C.V., %	11.2	7.2	10.6	11.2

[a] Whole, aboveground plant K at early heading.
[b] Trifoliolate leaf K concentration at R1 to R2 stage. Soybean leaf K concentrations and yields are the average of two cultivars.

Table 5. Rice (r) grain yields as affected by annual P and K rates for the in the long-term trials at the Rice Research Extension Center (RREC) in 2014.

Annual P or K rate	RREC-Pr Yield	RREC-Kr Yield	RREC-Kr Tissue K[a]
(lb K_2O or P_2O_5/acre/year)	----------- (bu/acre)	------------	(% K)
0	171	174	1.51
40	172	181	1.64
80	175	185	2.06
120	176	183	2.07
160	171	184	2.22
$LSD_{0.10}$	NS[b]	6.5	0.10
P-value	0.7982	0.0606	<0.0001
C.V., %	5.0	3.6	5.3

[a] Whole, aboveground plant sample at early heading.
[b] NS = not significant ($P > 0.10$).

Table 6. Soybean (s) tissue P and K concentrations and grain yields as affected by annual P and K rates for the in the long-term trials at the Rice Research Extension Center (RREC).

Annual K rate	RREC-Ps Leaf P[a]	RREC-Ps Yield	RREC-Ks Leaf K[a]	RREC-Ks Yield
(lb K_2O or P_2O_5/acre/year)	(% P)	(bu/acre)	(% K)	(bu/acre)
0	0.332	64	1.82	66
40	0.372	66	2.21	73
80	0.382	67	2.37	71
120	0.388	60	2.42	74
160	0.410	61	2.52	76
$LSD_{0.10}$	0.020	4.6	0.14	3.7
P-value	<0.0001	0.0900	<0.0001	0.0027
C.V., %	5.3	7.2	6.3	5.2

[a] Trifoliolate leaf P or K concentration at R1 to R2 stage.

Growing-Season Methane Fluxes and Emissions from a Silt Loam Soil as Influenced by Rice Cultivar

A.D. Smartt, C.W. Rogers, K.R. Brye, R.J. Norman, W.J. Smartt, J.T. Hardke, D.L. Frizzell, and E. Castaneda-Gonzalez

ABSTRACT

Rice (*Oryza sativa* L.) production systems have a greater global warming potential than upland row crops due to methane (CH_4) emissions resulting from anaerobic conditions of flooded soils. The objective of this study was to determine the influence of cultivar, specifically hybrids, on CH_4 fluxes and emissions from a silt loam soil. This study was conducted in 2014 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., on a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualfs). Four cultivars were evaluated: the three hybrids CLXL729, CLXL745, and XL753, and the pure-line Roy J. Gas samples were collected from enclosed-headspace gas sampling chambers at 0, 20, 40, and 60 min after chamber closure, and CH_4 fluxes were calculated from changes in headspace CH_4 concentration over time. Fluxes were determined weekly during the flood-retention period and every one to two days for one week following flood release. Only minor differences in CH_4 fluxes occurred between the three hybrid cultivars, while the pure-line cultivar (Roy J) resulted in significantly greater fluxes, especially late in the season. Peak CH_4 fluxes occurred just after heading and were greater from Roy J (7.9 mg CH_4-C/m^2/h) than the three hybrid cultivars (mean = 5.1 mg CH_4-C/m^2/h), which did not differ. A significant post-flood-release pulse occurred in all cultivars at four days after flood release. Seasonal CH_4 emissions were greater from Roy J (74.8 kg CH_4-C/ha/season) than from CLXL729, XL753, and CLXL745, which did not differ, and averaged 55.3, 53.0, and 48.9 kg CH_4-C/ha/season, respectively. Estimated CH_4 emissions in this study were 27% to 42% of the United States Environmental Protection Agency (USEPA) emission factor, indicating that CH_4 emissions from Arkansas rice production may be

substantially less than the EPA estimate. More data are needed in order to accurately quantify CH_4 emissions from Arkansas rice production.

INTRODUCTION

Rice cultivation was estimated as the third largest source of methane (CH_4) from the agricultural sector, which represented approximately 4% of total agricultural CH_4 emissions in the United States from 1990 to 2012 (USEPA, 2014). Enteric fermentation and manure management were the largest sources and accounted for 72% and 24% of agricultural CH_4 emissions, respectively (USEPA, 2014). Arkansas has the largest planted-rice area in the United States and accounted for 37% of the CH_4 emissions from rice cultivation, greatest among the rice-producing states.

Historically, the only factor used to adjust CH_4 emissions between states was acreage of ratoon crop grown in a state, which is known to have considerably greater emissions compared to a primary rice crop (Wang et al., 2013; USEPA, 2013). For all planted-rice acres grown as a primary rice crop, a single emission factor of 160 kg CH_4-C/ha/season was used until 2014 regardless of other factors known to influence emissions (Rogers et al., 2012; Brye et al., 2013; USEPA, 2013). However, the recently updated USEPA estimate now includes California-specific estimates for winter-flooded (202 kg CH_4-C/ha/season) and non-winter-flooded (101 kg CH_4-C/ha/season) rice fields (USEPA, 2014), and a single emission factor of 180 kg CH_4-C/ha/season for all other states' primary rice crop acres (USEPA, 2014).

The new non-California-rice emission factor estimate (USEPA, 2014) represents an 11% increase from the previous factor of 160 kg CH_4-C/ha/season (USEPA, 2013). The current estimate included the first study conducted in Arkansas' drill-seeded, delayed-flood production system using the cultivar Wells (Rogers et al., 2012); but, results from subsequent studies conducted in Arkansas (Adviento-Borbe et al., 2013, Brye et al., 2013; Rogers et al., 2013a,b; Rogers et al., 2014) were not published until after the current USEPA estimates were completed. Subsequent to the new EPA estimates (USEPA, 2014), cultivar selection has been shown to significantly impact CH_4 emissions (Rogers et al., 2013ab; Rogers et al., 2014), but cultivar selection is not currently accounted for in the USEPA CH_4 emissions estimate for a primary rice crop. This is particularly important because 48% of Arkansas rice acreage is planted with hybrid cultivars, with a single cultivar (CLXL745) alone representing 28% of the acreage (Hardke, 2014). Results from direct comparisons of hybrid rice to pure-line cultivars averaged across previous crop (i.e., rice or soybean) indicated a reduction in CH_4 emissions of 35% to 40% from hybrid rice as compared to two pure-line cultivars (Rogers et al., 2014).

The current research focused on comparing a single pure-line cultivar to several hybrids to investigate if differences existed in common hybrid cultivars grown in Arkansas. This study adds significant data from drill-seeded, delayed-flood rice production systems in Arkansas on a silt loam soil concerning cultivar effects on CH_4 emissions that will be important for future updates of the USEPA greenhouse gas inventory. Thus, the objective of this study was to evaluate hybrid rice effects on CH_4 emissions from a silt loam soil during the 2014 growing season. It was hypothesized that emissions would not differ among hybrid cultivars, but that hybrid cultivars would have significantly lower emissions as compared to a pure-line cultivar.

PROCEDURES

Research was conducted in 2014 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., on a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualfs). Field plots were 6-ft wide by 16-ft long arranged in a randomized complete block (RCB) design and were seeded in early May with the pure-line cultivar Roy J at a rate of 73 lb/acre and the hybrid cultivars, CLXL745, CLXL729, and XL753, at a rate of 30 lb/acre with 7-in row spacing. Nitrogen (N) was applied as urea in a two-way split application with the Roy J receiving 90 lb N/acre just prior to flooding and an additional 45 lb N/acre at panicle differentiation (PD). The cultivars XL753 and CLXL745 each received 120 lb N/acre and CLXL729 received 90 lb N/acre prior to flooding, and all three hybrid cultivars received an additional 30 lb N/acre during the late-boot stage. A flood depth of 2- to 4-inches was established at the 4- to 5-lf stage, within 1 day of preflood-N fertilization, and the flood was maintained until the flood was released at grain maturity in early September.

Soil samples were collected prior to flooding using a 1-inch-diameter push probe by combining five cores from the 0- to 4-inch depth in each plot. Samples were dried at 70 °C for 48 h and sieved through a 2-mm mesh screen prior to being analyzed for Mehlich-3 extractable nutrients (P, K, Ca, Mg, Fe, Mn, Na, S, Cu, and Zn; Spectro Analytical Instruments, Spectro Arcos ICP, Kleve, Germany). Total N and C were determined by high-temperature combustion using a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). Soil pH and electrical conductivity (EC) were determined potentiometrically on a 1:2 (m:v) soil-to-solution paste. Soil organic matter (OM) content was determined by loss on ignition. Bulk density samples were collected from the 0- to 4-inch depth using a 2-inch-diameter core chamber, dried at 70 °C for 48 h, weighed and ground to pass a 2-mm mesh screen for particle-size analysis using a modified 12-h hydrometer method (Gee and Or, 2002).

Enclosed-headspace chambers were used for collection of gas samples in field plots (Parkin and Venterea, 2010) at 0, 20, 40, and 60 min after chamber closure. Polyvinyl chloride chambers with an inner diameter of 11.75 inches and heights of 16, 24, and 40 inches were used to enclose rice plants and accommodate increasing plant heights over the growing season. Methane fluxes were determined weekly during flooded conditions by calculating rates of change in CH_4 concentration over time from headspace gas collected from each chamber. Methane fluxes were additionally determined every one to two days for one week following flood release. Gas samples were analyzed using an Agilent 6890-N gas chromatograph (Agilent Technologies, Santa Clara, Calif.). Season-long emissions were estimated by linear interpolation and numerical integration between measurement dates.

Initial soil properties and season-long emissions were analyzed by analysis of variance (ANOVA) in SAS v. 9.4 (SAS Institute, Cary, N.C.) using PROC Mixed based on a randomized complete block design. Similarly, CH_4 fluxes over time were analyzed by ANOVA based on a RCB repeated-measures design. Methane fluxes were analyzed separately prior to and following flood release due to differences in transport mechanisms and sampling frequency. When appropriate, means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level.

RESULTS AND DISCUSSION

Initial Soil Properties

Initial soil properties in the top 4 inches measured prior to flooding were generally unaffected by pre-assigned treatments (Table 1), with the exception of extractable Na ($P = 0.035$), extractable Mn ($P = 0.044$), and clay percentage ($P = 0.024$). However, the magnitude of these differences among pre-assigned treatment combinations, which amounted to 4.8 mg Na/kg (ppm), 11.5 mg Mn/kg (ppm), and 0.7% clay, likely had no practical or agronomic significance in this study. Extractable soil-P, -K, and -Zn were all within the optimum levels of 36 to 50 mg P/kg (ppm), 131 to 175 mg K/kg (ppm), and ≥ 4.1 mg Zn/kg (ppm) recommended for rice produced on a silt loam soil, indicating adequate levels of these nutrients for rice production based on University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations (Norman et al., 2013).

Seasonal Methane Fluxes

Methane fluxes from flooding to flood release differed among cultivars over time ($P < 0.001$; Table 2). Measured fluxes did not differ among the four cultivars during the first three weeks after flooding and only differed among the three hybrid cultivars at 56 days after flooding (DAF), where fluxes were less from CLXL745 than from the other two hybrids, which did not differ, and at 63 DAF, where fluxes were less from CLXL745 than from CLXL729, which were both not different from XL753 (Fig. 1). The pure-line cultivar, Roy J, resulted in fluxes greater than one and two of the hybrid cultivars on 28 and 35 DAF, respectively, and fluxes greater than all three hybrid cultivars during the four weeks following 50% heading.

Following flood release, cultivar impacted CH_4 fluxes ($P = 0.042$; Table 2). Averaged across time, Roy J had greater fluxes than CLXL745 and XL753, while CLXL729 did not differ from any of the cultivars. Similarly, sampling date impacted CH_4 fluxes ($P < 0.001$), where a significant CH_4 pulse occurred at 82 DAF (i.e., 4 days after flood release).

While the magnitudes of fluxes were greater from the pure-line cultivar late in the growing season, all four cultivars exhibited the same general trend where fluxes generally increased over time, peaking shortly after 50% heading at 7.9 mg CH_4-C/m^2/h for Roy J and 5.3, 5.2, and 4.8 mg CH_4-C/m^2/h for CLXL729, XL753, and CLXL745, respectively, which did not differ. Fluxes then declined during grain fill until a pulse occurred following flood release. Similar seasonal patterns have been observed in other studies, which suggest that root exudates increase during vegetative growth providing substrate for methanogenesis and decrease again during grain fill as resources are translocated to the grains (Sass et al., 1991a,b; Nouchi et al., 1994; Huang et al., 2002; Rogers et al., 2014). A similar trend of reduced fluxes from hybrid cultivars was observed by Rogers et al. (2014) where a standard stature pure-line cultivar (Taggart) and a hybrid cultivar (CLXL745) grown in a silt loam soil had peak fluxes of 15.6 and 8.3 mg CH_4-C/m^2/h, respectively. Similarly, Ma et al. (2010) observed reduced fluxes from a hybrid cultivar and attributed the lower emissions to greater CH_4 oxidation by methanotrophs in the rhizosphere, especially late in the season. The post-flood-release pulse of CH_4 that occurred in this study has been observed in previous studies (Denier van der Gon et al., 1996; Bossio et al., 1999; Adviento-Borbe et al., 2013; Brye et al., 2013; Rogers et al., 2013b, 2014) and is generally attributed to the escape of CH_4 from the soil as pores become dry and allow transport of previously entrapped gases.

Seasonal Methane Emissions

Seasonal CH_4 emissions were greater ($P = 0.001$) from Roy J (74.8 kg CH_4-C/ha/season) than from CLXL729, XL753, and CLXL745, which did not differ and averaged 55.3, 53.0 and 48.9 kg CH_4-C/ha/season, respectively. Similarly, Rogers et al. (2014) observed a 40% reduction in emissions from CLXL745 compared to Taggart. The reduced emissions from hybrid cultivars observed in this study, as well as by Rogers et al. (2014), may be a result of increased CH_4 oxidation in the rhizosphere of hybrid cultivars as suggested by Ma et al. (2010). Emissions measured in this study were 56% to 60% lower than emissions observed by Rogers et al. (2014) and only amounted to 27% to 42% of the current EPA emission factor. Low emissions observed in this study relative to those reported by Rogers et al. (2014) on a similar soil may be a result of lower sand content or greater soil-extractable P, both of which have been shown to result in reduced emissions (Sass et al., 1994; Lu et al., 1999). Results obtained by Adviento-Borbe et al. (2013), however, were consistent with this study where emissions of 46 kg CH_4-C/ha/season were observed from CLXL745 on a Dewitt silt loam in Arkansas. Grain yields were greater ($P < 0.001$) from XL753 (244 bu/acre) than from CLXL745, Roy J, or CLXL729, which did not differ and averaged 193, 189, and 188 bu/acre, respectively. Resulting yield-scaled emissions were greatest from Roy J and least from XL753.

SIGNIFICANCE OF FINDINGS

This study estimated total seasonal CH_4 emissions from rice produced on a silt loam soil under common Arkansas production practices to be 27% to 42% of the EPA emission factor and observed a 30% reduction in emissions from hybrid cultivars relative to a pure-line cultivar. This may be a substantial difference when considering the magnitude of Arkansas rice production coupled with the fact that a large portion of production is now utilizing high-yielding hybrid cultivars. Data obtained from this study, as well as other studies recently conducted in Arkansas, may allow the EPA to further refine emission factors and more closely represent emissions from mid-South rice production. It is important to continue investigating the impact of various influencing factors in an attempt to more accurately quantify CH_4 emissions and characterize the carbon footprint and future sustainability of rice production in Arkansas.

ACKNOWLEDGMENTS

Research for this project was supported by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Adviento-Borbe, M.A., C.M. Pittelkow, M. Anders, C. van Kessel, J.E. Hill, A.M. McClung, J. Six, and B.A. Linquist. 2013. Optimal fertilizer nitrogen rates and yield-scaled global warming potential in drill seeded rice. J. Environ. Qual. 42:1623-1634.

Bossio, D.A., W.R. Horwath, R.G. Mutters, and C. van Kessel. 1999. Methane pool and flux dynamics in a rice field following straw incorporation. Soil Biol. Biochem. 31:1313-1322.

Brye, K.R., C.W. Rogers, A.D. Smartt, and R.J. Norman. 2013. Soil texture effects on methane emissions from direct-seeded, delayed-flood rice production in Arkansas. Soil Sci. 178:519-529.

Denier van der Gon, H.A.C., N. van Breemen, H.U. Neue, R.S. Lantin, J.B, Aduna, M.C.R. Alberto, and R. Wassmann. 1996. Release of entrapped methane from wetland rice fields upon soil drying. Global Biogeochem. Cycl. 10:1-7.

Gee, G.W. and D. Or. 2002. Particle-size analysis. pp. 255-293. *In:* J.H. Dane and G.C. Topp (eds.). Methods of soil analysis. Part 4: Physical methods. 1st ed. SSSA, Madison, Wis.

Hardke, J.T. 2014. Trends in Arkansas rice production, 2013. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies, 2014. University of Arkansas Agricultural Experiment Station Research Series 617:13-23. Fayetteville, Ark.

Huang, Y., Y. Jiao, L. Zong, X. Zheng, R.L. Sass, and F.M. Fisher. 2002. Quantitative dependence of methane emission on soil properties. Nutr. Cycl. Agroecosys. 64:157-167.

Lu, Y., R. Wassmann, H.U. Neue, and C. Huang. 1999. Impact of phosphorus supply on root exudation, aerenchyma formation, and methane emission of rice plants. Biogeochemistry 47:203-218.

Ma, K., Q. Qiu, and Y. Lu. 2010. Microbial mechanism for rice variety control on methane emission from rice field soil. Global Change Biol. 16:3085-3095.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. pp. 69-102. *In:* J.T. Hardke (ed.). Arkansas rice production handbook. Misc. Publ. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, Ark.

Nouchi, I., T. Hosono, K. Aoki, and K. Minami. 1994. Seasonal variation in methane flux from rice paddies associated with methane concentration in soil water, rice biomass and temperature, and its modeling. Plant Soil 161:195-208.

Parkin, T.B. and R.T. Venterea. 2010. Chamber-based trace gas flux measurements. pp. 3-1--3-39 *In:* R. Follett (ed.). Sampling protocols. Accessed 25 Jan. 2012. Available at: www.ars.usda.gov/research/GRACEnet

Rogers, C.W., K.R. Brye, R.J. Norman, T. Gasnier, D. Frizzell, and J. Branson. 2012. Methane emissions from a silt-loam soil under direct-seeded, delayed-flood rice management. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Rice Research Studies, 2011. University of Arkansas Agricultural Experiment Station Research Series 600:240-247. Fayetteville, Ark.

Rogers, C.W., K.R. Brye, R.J. Norman, A.D. Smartt, A.M. Fulford, and D. Frizzell. 2013a. Seasonal pattern of methane fluxes from a silt-loam soil as affected by previous crop and cultivar. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Rice Research Studies, 2011. University of Arkansas Agricultural Experiment Station Research Series 609:272-279. Fayetteville, Ark.

Rogers, C.W., K.R. Brye, R.J. Norman, E.E. Gbur, J.D. Mattice, T.B. Parkin, and T.L. Roberts. 2013b. Methane emissions from drill-seeded, delayed-flood rice production on a silt-loam soil in Arkansas. J. Environ. Qual. 42:1059-1069.

Rogers, C.W., K.R. Brye, A.D. Smartt, R.J. Norman, E.E. Gbur, and M.A. Evans-White. 2014. Cultivar and previous crop effects on methane emissions from drill-seeded, delayed-flood rice production on a silt-loam soil. Soil Sci. 179:28-36.

Sass, R.L., F.M. Fisher, P.A. Harcombe, and F.T. Turner. 1991a. Mitigation of methane emissions from rice fields: Possible adverse effects of incorporated rice straw. Global Biogeochem. Cycl. 5:275-287.

Sass, R.L., F.M. Fisher, S.T. Lewis, F.T. Turner, and M.F. Jund. 1994. Methane emission from rice fields: Effects of soil properties. Global Biogeochem. Cycl. 8:135-140.

Sass, R.L., F.M. Fisher, F.T. Turner, and M.F. Jund. 1991b. Methane emissions from rice fields as influenced by solar radiation, temperature, and straw incorporation. Global Biogeochem. Cycl. 5:335-350.

USEPA. United States Environmental Protection Agency. 2013. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2011. Accessed 10 Mar. 2014. Available at: http://www.epa.gov/climatechange/Downloads/ ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf

USEPA. United States Environmental Protection Agency. 2014. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2012. Accessed 12 Dec. 2014. Available at: http://www.epa.gov/climatechange/Downloads/ ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

Wang, J.J., S.K. Dodla, S. Viator, M. Kongchum, S. Harrison, S.D. Mudi, S. Liu, and Z. Tian. 2013. Agriculture field management practices and greenhouse gas emissions from Louisiana soils. Louisiana Agri. Spring, 2013:8-9.

Table 1. Mean soil physical and chemical properties (n = 16) prior to flood establishment in the top 4 inches of a Dewitt silt loam soil during the 2014 growing season at the Rice Research and Extension Center near Stuttgart, Ark.

Soil property	Mean (± standard error)
pH	6.45 (0.02)
Sand (%)	7.3 (0.12)
Silt (%)	75.6 (0.12)
Clay (%)	17.1 (0.10)
Bulk density (g cm^{-3})	1.34 (0.01)
Electrical conductivity (µmhos cm^{-1})	201 (5)
Mehlich-3 Extractable Nutrients (mg kg^{-1}, or ppm)	
P	47.7 (2.8)
K	139 (3.1)
Ca	1648 (17)
Mg	158 (1)
Fe	364 (2.2)
Mn	246 (2)
Na	54.1 (0.9)
S	12.2 (0.4)
Cu	1.3 (0.01)
Zn	4.8 (0.5)
Organic matter (g kg^{-1})	19.9 (0.1)
Organic matter (mg ha^{-1})	26.8 (0.2)
Total N (g kg^{-1})	0.89 (0.01)
Total N (mg ha^{-1})	1.19 (0.02)
Total C (g kg^{-1})	8.9 (0.12)
Total C (mg ha^{-1})	11.9 (0.2)
C:N ratio	10.0 (0.2)

Table 2. Analysis of variance summary of the effects of cultivar, time, and their interaction on methane fluxes from a silt loam soil during the 2014 growing season at the Rice Research and Extension Center near, Stuttgart, Ark.

Source of variation	Flooding to flood release	Post-flood release
Cultivar	0.002	0.042
Time	< 0.001	< 0.001
Cultivar × time	< 0.001	0.156

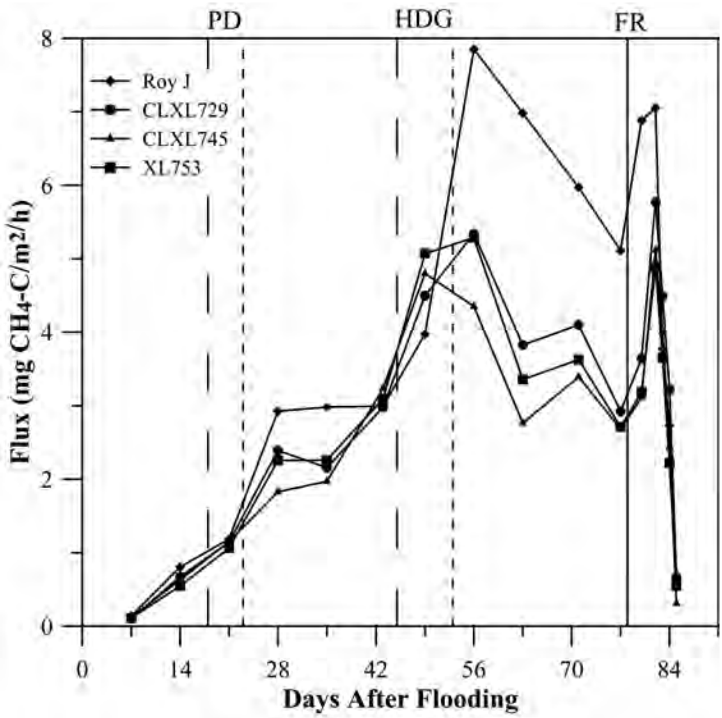


Fig. 1. Growing-season CH_4 fluxes from four cultivars measured from a Dewitt silt loam soil at the Rice Research and Extension Center near Stuttgart, Ark. Vertical lines on the graph indicate approximate dates of panicle differentiation (PD) and 50% heading (HDG) for the hybrid cultivars (long-dashed lines) and pure-line cultivar (short-dashed lines) as well as the date of flood release (FR). Least significant difference for the same cultivar = 0.679 mg CH_4-C/m^2/h and for different cultivars = 0.824 mg CH_4-C/m^2/h.

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2014

S.M. Williamson, T.L. Roberts, C.L. Scott, N.A. Slaton, J. Shafer and C.E. Greub

ABSTRACT

Seeking to fine-tune nitrogen (N) application, increase economic returns, and decrease environmental N loss, some Arkansas farmers are turning away from blanket N recommendations based on cultivar, soil texture, and previous crop and have begun using the Nitrogen Soil Test for Rice (N-STaR) to determine their field-specific N rates. First developed in 2011, Roberts et al. correlated direct steam distillation results from 18-inch silt loam soil samples to plot-scale N response trials and subsequently performed field-scale validation. The N-STaR program has since been correlated and calibrated for clay soils, using a 12-inch depth soil sample, both in small-plot scale and field-scale validation, and has been offered to the public since 2012 for silt loams and 2013 for clay soils. To summarize the samples submitted to the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Laboratory during 2014, samples were categorized by county and soil texture. Samples were received from 24 Arkansas counties, with Arkansas and Randolph counties evaluating the largest number of fields, with 59 and 30 fields, respectively. The samples received were from 192 silt loam fields and 41 clay fields. The N-STaR N-rate recommendations were then compared to the producer's estimated N rate, the 2014 Recommended Nitrogen Rates and Distribution for Rice Varieties in Arkansas, and the standard Arkansas N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils and divided into the following categories: those where N-STaR recommended a decrease in N rate, no change in N rate recommended, or N-STaR recommended an increase in the N rate. In all three comparisons, soil texture was found to be a significant factor ($P < 0.0001$) in the fields where N-STaR recommended the N rate be decreased, but was found to not be significant in the fields that N-STaR recommended an increase in N rate. County

was found to be a significant factor in fields that N-STaR recommended a decrease ($P < 0.0001$) and an increase ($P < 0.05$) in N rate compared to the producer's estimated N rate, but was found to only be significant in the fields where N-STaR recommended a decrease in N rate compared to the standard N-rate recommendation ($P < 0.0001$) and the variety N-rate recommendation comparison ($P < 0.05$).

INTRODUCTION

Historically, nitrogen (N) recommendations for rice in Arkansas were based on soil texture, cultivar, and previous crop—often resulting in over-fertilization, thus decreasing possible economic returns and increasing environmental N loss. For years researchers have tried to develop a soil test that would allow them to better predict the actual N needs for a particular field. After many years of research at the University of Arkansas, the long quest for soil-based N recommendation for rice came to fruition in 2010 when investigators expanded on research at the University of Illinois which used organic-N content in the form of amino sugars to predict corn response to N fertilizer (Mulvaney et al, 2006). University scientists correlated several years of direct steam distillation (DSD) results obtained from 18-inch soil samples (Roberts et al., 2009), which quantifies the amount of N that will be plant available to rice during the growing season, to plot-scale N response trials across the state and developed a site-specific, soil-based N test for Arkansas rice (Roberts et al., 2011). Direct-seeded, delayed-flooded rice production, with proper flood management and the use of ammonium-based fertilizers and best management practices, has a consistent N mineralization rate and one of the highest N use efficiencies of any cropping system, therefore lending itself to a high correlation of mineralizable N to yield response (Roberts et al., 2011). After extensive field testing, the Nitrogen Soil Test for Rice (N-STaR), became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab in Fayetteville, Ark. Later, researchers correlated DSD results from 12-inch soil samples to N response trials on clay soils (Fulford et al., 2013), and N-STaR rate recommendations became available for clay soils in 2013.

PROCEDURES

In an effort to summarize the effect of the N-STaR program in Arkansas, samples submitted to the University of Arkansas N-STaR Soil Testing Lab during 2014 were categorized by county and soil texture. The N-STaR N-rate recommendations for these samples were then compared to the producer's estimated N rate if supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2014 Recommended Nitrogen Rates and Distribution for Rice Varieties in Arkansas (Roberts and Hardke, 2014), or to the standard Arkansas N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. Samples were then divided into three categories—those where N-STaR recommended a decrease in N rate, no change in recommended N rate, or N-STaR recommended an increase in the N rate. The resulting data was analyzed using JMP v. 10 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Samples were received from 233 fields which represented 62 farmers across 24 Arkansas counties. Arkansas and Randolph counties evaluated the largest number of fields, with 59 and 30 fields, respectively. The samples received were from 195 silt loam fields and 41 clay fields (Table 1). While there were 7 farmers that submitted more than 10 fields for analysis, the average number of fields submitted per farmer was 3.76, with 24 farmers only submitting samples from one field each. There were 14 farmers who submitted samples in 2013 that also submitted samples in 2014.

Sixteen of the submitted fields had no estimated N rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the farmer's estimated N rate. Of those compared, N-STaR recommended a decrease in the N rate for 158 fields (~73% of the remaining 217 fields submitted) with an average decrease of 35.6 lb N/acre (Table 2). No change in N recommendation was found for 3 fields, while N-STaR recommended an increase in N rate for 56 fields (26%), with an average increase of 12.6 lb N/acre. Of the fields where there was a decrease in the N-rate recommendation in this comparison, 127 of those were from silt loam fields and 31 came from fields labeled as clay, with an average decrease of 28 lb N/acre for silt loams and an average decrease of 66.5 lb N/acre for the clay soils. The fields where an increase in recommendation was found were from 50 silt loams and 6 clays with an average of 12.8 and 12 lb N/acre, respectively. Soil texture was found to be a significant factor ($P < 0.0001$) for the fields that resulted in a decrease from the producer's estimate to the N-STaR recommendation but was not significant in the fields that resulted in an increase in N rate. The difference in significance may be due to soil texture variability, soil texture classification errors, and the differences in sample depth and the N-STaR calculations for the two textures. The N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the farmer's classification of their field. County was found to be a significant factor in fields that showed both an increase ($P < 0.05$) and a decrease ($P < 0.0001$) in the N-rate recommendation suggesting that while certain areas of the state do require more N to maintain yields, other areas may be prone to N savings potential due to cropping systems and soil series.

The N-STaR recommendation was also compared to the 2014 Recommended Nitrogen Rates and Distribution for Rice Varieties in Arkansas (Roberts and Hardke, 2014). The variety recommendations were adjusted for soil texture as recommended by adding 30 lb N/acre for rice grown on clay soils and then compared to the N rates determined by N-STaR. The 22 fields that did not list a variety on the N-STaR Sample Submission Sheet were excluded from this comparison. The Nitrogen Soil Test for Rice recommended a decrease in the N rate for 148 fields (70% of the 211 fields) with an average decrease of 33.8 lb N/acre (Table 3). No change in N recommendation was found for 8 fields; while for 55 of the fields (26%), N-STaR recommended an increase in the N rate, with an average increase of 16 lb N/acre. Again, county and soil texture were a significant factor ($P < 0.0001$) in the fields where N-STaR recommended a decrease in N rate. However, only county was found to be a significant factor ($P < 0.05$) in the fields where N-STaR recommended an increase in N rate.

County was found to be a significant ($P < 0.05$) factor only in the fields with a decrease in N rate when the N-STaR recommendation was compared to Arkansas' standard N-rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. Likewise, soil texture was found to be a significant factor ($P < 0.0001$) in the fields with a decrease in N rate. County and soil texture were not significant in the fields where an increase in N rate was recommended by N-STaR; however it should be noted that there were no clay fields that resulted in an increase in N rate in this comparison (Table 1). Of the fields in this comparison, N-STaR recommended a decrease in the N rate for 184 fields (79% of the remaining 233 fields submitted) with an average decrease of 35.2 lb N/acre. No change in N recommendation was found for 9 fields; while for 40 fields (17%), N-STaR recommended an increase in N rate, with an average increase of 12 lb N/acre.

The same trends in N-STaR sample submission are present in 2014 as they were in 2013. Arkansas County was again the county with the highest number of samples submitted to the N-STaR lab for analysis (Fig. 1). Just as in 2013, Arkansas County had both the highest number of fields submitted for evaluation, 59, and the highest number of fields for which N-STaR recommended a decrease in N rate, 41 fields or 69%, with an average decrease of 27.5 lb N/acre (Table 2). Randolph, Greene, and Craighead counties exhibited the same general trend with 70%, 60%, and 60% of the samples submitted resulting in a decrease in N-STaR N-rate recommendation with an average decrease of 22.4, 30.4, and 20.4 lb N/acre, respectively.

It is interesting to note that Randolph, Greene, and Craighead counties, while submitting the larger number of samples to the N-STaR lab (Table 2, Fig. 1), were not among the top rice-producing counties in Arkansas for 2014. Poinsett, Jackson, and Lawrence counties, while the highest in 2014 rice acreage, only submitted a small number of fields. More samples will need to be submitted from these areas to evaluate the N-STaR recommendation trends in those counties.

SIGNIFICANCE OF FINDINGS

These results show the importance of the N-STaR program to Arkansas rice producers and can help target areas of the state that would most likely benefit from its incorporation. Standard recommendations and cultivar recommendations will continue to be good ballparks for N rates, but field-specific N rates continue to offer the best estimate of the N needed for each particular field regardless of soil texture or cultivar selection. The N-STaR Soil Testing Lab is currently working to fine-tune how soils are classified to better help producers choose the correct sampling depth for their field.

ACKNOWLEDGMENTS

This research was funded by Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. Sincere gratitude is extended to the employees of the University of Arkansas N-STaR Soil Testing Lab and the hourly personnel who spent many hours conducting the analysis of N-STaR samples.

LITERATURE CITED

Fulford, A.M., T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson Jr., T.W. Walker, D.L. Frizzell, C.E. Greub, C.W. Rogers, S.M. Williamson, M.W. Duren, and J. Shafer. 2013. Evaluation of the Illinois Soil Nitrogen Test and the Nitrogen-Soil Test for Rice Grown on Clayey Soils. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:204-212. Fayetteville, Ark.

Mulvaney, R.L., S.A. Khan, and T.R. Ellsworth. 2006. Need for a soil-based approach in managing nitrogen fertilizers for profitable corn production. Soil Sci. Soc. Am. J. 70:172-182.

Roberts, T.L., R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2009. Changes in alkaline hydrolyzable nitrogen distribution with soil depth: Implications for fertilizer correlation and calibration. Soil Sci. Soc. Am. J. 73:2143-2150.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton and C.E. Wilson Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1-12.

Roberts, T.L. and J.T. Hardke. 2014. 2014 Recommended Nitrogen Rates and Distribution for Rice Varieties in Arkansas. University of Arkansas Cooperative Extension Service. Accessed 2 February 2015. Available at: http://www.uaex.edu/farm-ranch/crops-commercial-horticulture/rice/

Table 1. Distribution and change in N rate recommended by the Nitrogen Soil Test for Rice (N-STaR) compared to the standard N-rate recommendation based on soil texture.

		N-STaR recommendation				
		Decreased		Increased		
Soil type	No. of fields submitted	Fields	Mean N decrease	Fields	Mean N increase	No change in recommendation
		(no.)	(lb/acre)	(no.)	(lb/acre)	
Clay	41	41	64.5	-	-	-
Silt loam	192	143	26.7	40	12.7	9
Total	233	184	35.2	40	12.7	9

Table 2. Distribution and change in N rate recommended by the Nitrogen Soil Test for Rice (N-STaR) compared to the producer's estimated N rate by county.

		N-STaR recommendation				
		Decreased		Increased		
Soil type	No. of fields submitted	Fields	Mean N decrease	Fields	Mean N increase	No change in recommendation
		(no.)	(lb/acre)	(no.)	(lb/acre)	
Arkansas	59	41	27.5	11	10.3	1
Chicot	4	4	25.0	-	-	
Clay	1	1	55.0	-	-	
Conway	3	1	15.0	2	5.0	
Craighead	23	14	20.4	7	7.6	1
Crittenden	4	4	77.5	-	-	
Cross	3	1	115.0	2	7.0	
Desha	10	7	61.1	3	24.0	
Drew	1	1	55.0	-	-	
Greene	23	14	30.4	9	12.2	
Independence	1	-	-	1	5.0	
Jackson	14	9	72.8	3	15.0	
Jefferson	3	2	32.5	-	-	
Lawrence	5	2	12.5	3	21.7	
Lee	2	2	47.5	-	-	
Lincoln	3	3	27.3	-	-	
Lonoke	18	14	57.9	3	23.3	1
Phillips	3	2	15.0	1	15.0	
Poinsett	8	4	25.7	4	11.8	
Prairie	6	4	12.5	1	25.0	
Randolph	30	21	22.4	6	10.8	
St. Francis	2	2	30.0	-	-	
Tate	2	-	-	-	-	
White	5	5	53.0	-	-	
Total	217[a]	158	35.6	56	12.6	3

[a] Sixteen fields did not list an estimated N rate on their N-STaR Sample Submission Sheet.

Table 3. Distribution and change in N rate recommended by the Nitrogen Soil Test for Rice (N-STaR) compared to the standard N-rate recommendation for various rice cultivars in Arkansas.

		N-STaR recommendation				
		Decreased		Increased		
Soil type	No. of fields submitted	Fields	Mean N decrease	Fields	Mean N increase	No change in recommendation
		(no.)	(lb/acre)	(no.)	(lb/acre)	
Caffey	14	9	11.1	3	13.3	2
Cheniere	1	1	10	-	-	-
CL111	4	4	35	-	-	-
CL151	17	11	40	6	18.3	-
CL152	3	3	25	-	-	-
CLXL729	9	1	65	8	22.5	-
CLXL745	41	37	38.4	1	5	3
CLXP4534	1	-	-	1	45	-
Francis	2	1	115	1	5	-
Jupiter	44	31	29.2	11	11.8	2
Mermentau	10	9	27.8	1	15	-
Rex	2	2	60	-	-	-
Roy J	25	11	48.6	13	19.2	1
Wells	7	5	38	2	12.5	-
XL723	1	-	-	1	5	-
XL753	30	23	27.4	7	10	-
Total	211[a]	148	33.8	55	16	8

[a] Twenty-two fields did not list a variety on their N-STaR Sample Submission Sheet.

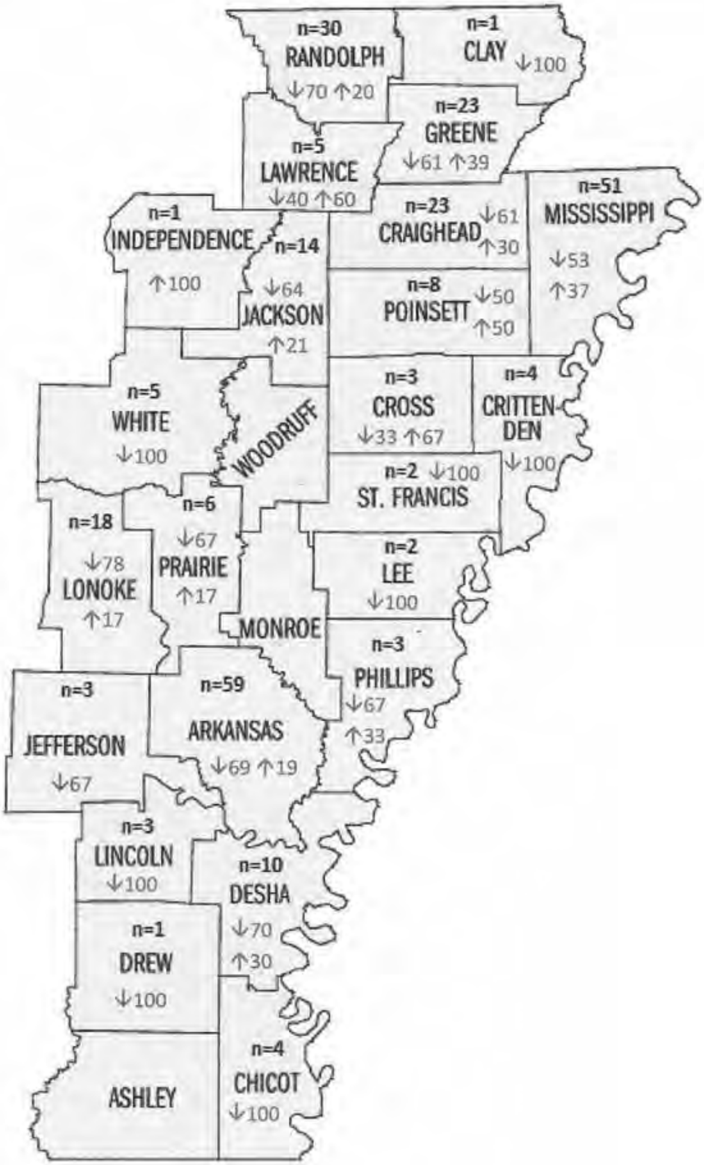


Fig. 1. Percent of samples submitted by county that the Nitrogen Soil Test for Rice (N-STaR) recommended either a decrease or an increase in N rate compared to the standard N-rate recommendation.

Microbial Prevalence on Freshly Harvested Long-Grain Hybrid, Long-Grain Pure-Line, and Medium-Grain Rice

G.G. Atungulu, S. Thote, H. Zhong, A. Okeyo,
A. Couch, S. Sadaka, and T. Siebenmorgen

ABSTRACT

Information regarding the prevalence of microorganisms on freshly harvested rice is vital for developing effective, low-temperature, natural air in-bin drying and storage strategies that reduce microbial growth thereby mitigating mycotoxin contamination. In this study, a survey was conducted to determine the effect of factors such as rice cultivar, geographic location, and harvest season and time on the prevalence of microorganisms on rough rice. Total (ground sample) and surface aerobic plate counts (APC) and mold counts were studied for freshly harvested long-grain hybrid (XL723 and XL753), long-grain pure-line (CL152 and RoyJ), and medium-grain (Caffey and Jupiter) rice cultivars grown in 2013 and 2014 at four Arkansas locations (Stuttgart, Rohwer, Colt, and Keiser). The study concluded that the APCs and mold counts significantly depended on the rice cultivars and harvest locations. Also, the geographic location where rice was grown had a significant effect on the level of microbial contamination on the rice kernels at harvest. These findings could benefit the rice industry by helping to develop effective strategies for drying, storage and/or decontamination of rice, thereby helping to prevent mycotoxin development.

INTRODUCTION

The changes in rice cultivars brought about by breeding improvement efforts can have effects on the vulnerability of the grain to invasion by microorganisms in the field and storage. The microbial invasions, especially in high-temperature and high-humidity environments may result in considerable losses in quantity and quality of rice. Long-grain hybrid, long-grain pure-line, and medium-grain rough rice each require different growing conditions and have distinctive physical characteristics, which may support microbial growth on the grain invariably.

Freshly harvested rice may contain microorganisms such as yeast, fungal molds, and bacteria (Atungulu et al., 2014). Of these, fungal mold contamination poses the greatest problem to grain producers, processors, and consumers. Under certain stressful conditions of temperature, relative humidity (RH), and storage durations, some fungal molds may produce mycotoxins (Frazier, 1967; Atungulu et al., 2014). Some older literature suggested that storage fungi do not invade rice to any significant degree in the field even when harvest is delayed by heavy rainfall; however, newer research indicates that some storage fungi invade grain in the field contaminating it to appreciable levels before harvest (Tripathi, 1975; Anderson et al., 1975; Lillehoj et al., 1976; Dickens, 1977; Wilson et al., 1979; Zuber and Lillehoj, 1979; King and Scott, 1982; Atungulu et al., 2014).

Rough rice in the U.S. is mostly dried using high-temperature, cross-flow drying systems (Schluterman and Siebenmorgen, 2004). However, in recent years, a new equilibrium moisture content-controlled drying technology for low-temperature air drying and storage of rough rice has received increased attention. Under certain drying and storage scenarios, it is possible that rice in the upper layers in the bins may fail to dry in a timely manner leading to fungal mold growth and development of mycotoxins. Understanding the prevalence of microbes on different rice cultivars to be placed in the new bin drying systems is very crucial to making good recommendations regarding drying and storage operations.

The objectives of this study were to determine: (1) the prevalence of aerobic bacteria and molds on the surface (surface counts) and throughout (total counts) freshly harvested rice, and (2) how factors such as rice growing location, cultivar, and harvest period influence the microbial prevalence.

PROCEDURES

Samples

Rice samples used in this research were harvested for two consecutive years between September and October, 2013 and 2014. The different cultivars were grown in randomly spaced experimental plots owned by the University of Arkansas System Division of Agriculture at four Arkansas locations: Rice Research and Extension Center near Stuttgart, Ark.; Rohwer Research Station near Rohwer, Ark.; Pine Tree Research Station near Colt, Ark.; and Northeast Research and Extension Center, Keiser, Ark. To avoid cross contamination that could result from equipment used at harvest and processing, rice panicles were hand-harvested and manually threshed in a sterile environment. The moisture content (MC) and water activity of the rice samples were determined using the method described by Jindal and Siebenmorgen (1987).

Microbial Analysis

The Official Methods of Analysis (AOAC) methods 990.12 (2005) and 997.02 (2002) for the 3M Petrifilm Aerobic Count Plates and 3M Petrifilm Mold Count Plates (3M Microbiology Product, Minneapolis, Minn.) were used to determine the rough-rice total (ground sample) and surface microbial counts. The suspensions were prepared by masticating the rice samples at two different settings (Silver Panoramic, iUL, S.A., Barcelona, Spain). The setting of 15 s and 0.5 stroke/s was used to dislodge surface microbes without breaking the rice husk for the surface microbial counts. For total microbial counts determination, the masticator was set at 240 s and 0.5 stroke/s, allowing the rice samples to be pulverized into powder for total microbial load analysis. The successive dilutions were made by mixing 1 mL of the original mixture with 9 mL of phosphate-buffered dilution water. For total and surface mold counts, 10^{-4} to $10^{-7}\times$ and 10^{-3} to $10^{-6}\times$ dilutions were plated, respectively. For total and surface aerobic plate counts (APCs), 10^{-4} to $10^{-7}\times$ and 10^{-5} to $10^{-8}\times$ dilutions were plated, respectively. After the recommended incubation periods, the colony forming units (CFUs) on each plate were calculated using the following formula:

$$T_{cfu} = \frac{P_{CFU}}{D_r} \qquad \text{Eq. 1}$$

where, T_{cfu} is total CFUs per gram of rice (CFUs/g), P_{CFU} is CFUs counted on plate per gram of rice (CFUs/g), and D_r is the dilution factor.

For the studied rice samples, preliminary results showed that yeast counts were very low with nearly none detected even with $10^{-10}\times$ dilution. Therefore, yeast count was not reported in this research.

Statistical Analysis

Linear regression, analysis of variance, and Student's *t* test (least significant difference test) were performed with statistical software JMP v. 10.0.0 (SAS Institute Inc., Cary, N.C.) to determine significant differences within and among samples. Level of significance (α) was set at 5% for comparing means of total APCs, surface APCs, total mold counts, and surface mold counts.

RESULTS AND DISCUSSION

Rice Harvest Moisture Content and Water Activity

The mean MCs of rough-rice samples at harvest are shown in Table 1. Rough rice harvested early in the season should have slightly higher MC than that harvested late in the season unless rainy weather affects the MC. During this study, rain fell late in the 2013 season. As a result, rough-rice cultivars (Roy J, CL152, XL753, and XL723) which were harvested earlier in the harvest season at Stuttgart had slightly higher MC compared to those harvested later. A similar trend was observed for water activity values of the rice samples (Roy J, CL152, XL753, and XL723). In 2014 harvest season, all the late-harvest rice samples had significantly lower MC than early-harvest samples at Stuttgart.

Microbial Load on Rice Grown at Different Locations

For both years, rough-rice samples harvested from Keiser had significantly lower APCs and mold counts compared to samples from the other locations; whereas, rice samples harvested from Rohwer in 2013 tended to contain the greatest levels of total and surface APCs and mold counts (Figs. 1a and 1b). Geographically, both Keiser and Rohwer locations lie in the Delta ecological zone, but are located in northeast Arkansas and southeast Arkansas, respectively. The major difference between the farming practices in Keiser and Rohwer are rice planting dates and seeding rates. In Rohwer, rice is planted earlier in April, whereas in Keiser planting is done in May; this variation also shifts the harvest dates to late September and late October. Therefore, varying weather conditions such as prevailing temperature, rainfall, and RH during the rice growing and harvest season may result in the significant differences observed in the microbial loads.

Microbial Distribution on Different Rice Cultivars

Figure 2 demonstrated that for 2013, long-grain hybrid cultivars had significantly lower APCs and mold counts than other cultivars ($P < 0.05$); whereas, medium-grain cultivars had significantly greater mold counts than all the other cultivars ($P > 0.05$) (Fig. 2a). In 2014, the hybrid cultivar had the lowest surface and total APC and mold counts (Fig. 2b).

Regression Analysis

Least square regression and effective test results illustrated that growing location and water activity levels significantly affected ($P < 0.0001$) the total and surface APCs and mold counts regardless of the cultivar. Different growing locations have different soil type, rainfall, and temperature which could affect mold growth.

SIGNIFICANCE OF FINDINGS

The findings from this study provide baseline information which is very helpful in modeling kinetics of microbial growth during rice storage in on-farm bins. The information may be useful to guide decisions on drying and storage conditions of rice to avoid mold growth leading to mycotoxin contamination.

ACKNOWLEDGMENTS

The authors greatly appreciate the Arkansas Rice Research and Promotion Board for financially supporting this research, Redentor Burgos, Brandon Griggs, B. Bluhm, and Kristen Gibson (of the University of Arkansas System Division of Agriculture) for support during the research. The authors appreciate the assistance of the agronomic crews led by Donna Frizzell, Eddie Castaneda, Mike Duren and Shawn Clark in conducting this research.

LITERATURE CITED

AOAC. Official Methods of Analysis 997.02. 2002. Yeast and Mold Counts in Foods. AOAC. Intl.

AOAC. Official Methods of Analysis 990.02. 2005. Aerobic Plate Count in Foods. AOAC. Intl.

Anderson, H.W., E.W. Nehring, and W.R. Wichser. 1975. Aflatoxin contamination of corn in the field. J. of Agric. and Food Chem. 23(4):775-82.

Atungulu, G.G., Zhong, H., and Siebenmorgen, T. 2014. Survey of factors affecting Microorganisms on Freshly-harvested Rice. 2014 ASABE and CSBE | SCGAB Annual International Meeting, July 13-16, 2014, Montreal, Quebec, Canada.

Dickens, J.W. 1977. Aflatoxin occurrence and control during growth, harvest and storage of peanuts. pp. 99-105. *In:* J.V. Rodricks, C.W. Hesseltine, and M.A. Mehlman (eds). Mycotoxins in Human and Animal Health. Pathotox Publishers, Inc., Park Forest South, Ill.

Frazier, W.C. 1967. Food Microbiology. New York. McGraw-Hill Book Company, Inc.

Jindal, V.K. and T.J. Siebenmorgen. 1987. Effects of oven temperature and drying time on rough rice moisture content determination. Trans. ASAE. 30(4):1185-1192.

King, S.B. and G.E. Scott. 1982. Field inoculation techniques to evaluate maize for reaction to kernel infection by *Aspergillus flavus*. Phytopathology. 72(7):782-785.

Lillehoj, E.B., W.F. Kwolek, A. Manwiller, J.A. Durant, J.C. LaPrade, E.S. Homer, J. Reid, and M.S. Zuber. 1976. Alfatoxin production in several corn hybrids grown in South Carolina and Florida. Crop Sci. 16(4):483-485.

Schluterman, G. and T.J. Siebenmorgen. 2004. Air and rice property profiles within a commercial cross-flow dryer. Appl. Eng. in Agric. 20(4):487-494.

Tripathi, R.K. 1975. Head fungi of sorghum, phytotoxins and their effects on seed germination. Indian Phytopathol. 27:499-501.

Wilson, D.M., W.W. McMillian, and N.W. Widstrom. 1979. Field aflatoxin contamination of corn in South Georgia. J. Amer. Oil Chem. Soc. 56(9):798-99.

Zuber, M.S. and E.B. Lillehoj. 1979. Status of the aflatoxin problem in corn. J. Environ. Qual. 8(1):1-5.

Table 1. Moisture content (%, w.b.) and water activity (inside parentheses) of rice at harvest (n = 3).

		Location				
Year	Cultivar	Stuttgart 1[a]	Stuttgart 2[b]	Colt	Rohwer	Keiser
2013	Jupiter	21.4 ± 2.4 (0.96 ± 0.00)	23.7 ± 0.7 (0.94 ± 0.00)	25.8 ± 2.0 (0.91 ± 0.00)	28.9 ± 0.7 (0.96 ± 0.01)	24.2 ± 0.7 (0.94 ± 0.01)
	Caffey	27.3 ± 0.4 (0.95 ± 0.00)	23.1 ± 0.4 (0.93 ± 0.00)	29.3 ± 0.5 (0.96 ± 0.00)	28.2 ± 0.6 (0.96 ± 0.01)	22.0 ± 1.1 (0.92 ± 0.01)
	RoyJ	21.4 ± 1.1 (0.92 ± 0.01)	22.5 ± 0.7 (0.93 ± 0.00)	20.8 ± 0.3 (0.91 ± 0.01)	20.7 ± 0.9 (0.87 ± 0.01)	22.2 ± 0.8 (0.93 ± 0.01)
	CL152	21.4 ± 1.1 (0.90 ± 0.01)	22.7 ± 0.3 (0.94 ± 0.00)	22.6 ± 0.7 (0.92 ± 0.01)	19.8 ± 0.9 (0.85 ± 0.01)	20.8 ± 0.3 (0.92 ± 0.01)
	XL753	20.7 ± 0.7 (0.91 ± 0.01)	22.3 ± 0.51 (0.93 ± 0.00)	22.8 ± 1.5 (0.89 ± 0.03)	21.0 ± 0.7 (0.88 ± 0.02)	20.0 ± 0.3 (0.90 ± 0.01)
	XL723	19.1 ± 0.7 (0.88 ± 0.01)	21.4 ± 0.2 (0.93 ± 0.00)	21.4 ± 0.68 (0.85 ± 0.03)	18.6 ± 1.0 (0.87 ± 0.01)	19.0 ± 0.4 (0.89 ± 0.00)
2014	Jupiter	26.5 ± 0.5 (0.87 ± 0.02)	18.9 ± 0.3 (0.76 ± 0.03)	29.1 ± 1.4 (0.89 ± 0.01)	29.1 ± 1.0 (0.9 ± 0.02)	28.4 ± 1.0 (0.89 ± 0.01)
	Caffey	23.8 ± 0.3 (0.85 ± 0.01)	17.8 ± 0.7 (0.78 ± 0.0)	27.8 ± 0.8 (0.87 ± 0.01)	29.9 ± 0.9 (0.90 ± 0.04)	25.9 ± 0.6 (0.85 ± 0.01)
	RoyJ	22.4 ± 0.3 (0.85 ± 0.01)	16.3 ± 0.5 (0.74 ± 0.02)	26.2 ± 3.3 (0.84 ± 0.01)	26.7 ± 1.7 (0.85 ± 0.01)	23.1 ± 1.6 (0.83 ± 0.01)
	XL753	19.5 ± 0.2 (0.82 ± 0.00)	16.0 ± 1.1 (0.73 ± 0.04)	22.9 ± 1.4 (0.84 ± 0.01)	23.1 ± 0.3 (0.84 ± 0.01)	20.2 ± 1.4 (0.82 ± 0.01)

[a] Samples harvested early in the harvest season.
[b] Samples harvested late in the harvest season.

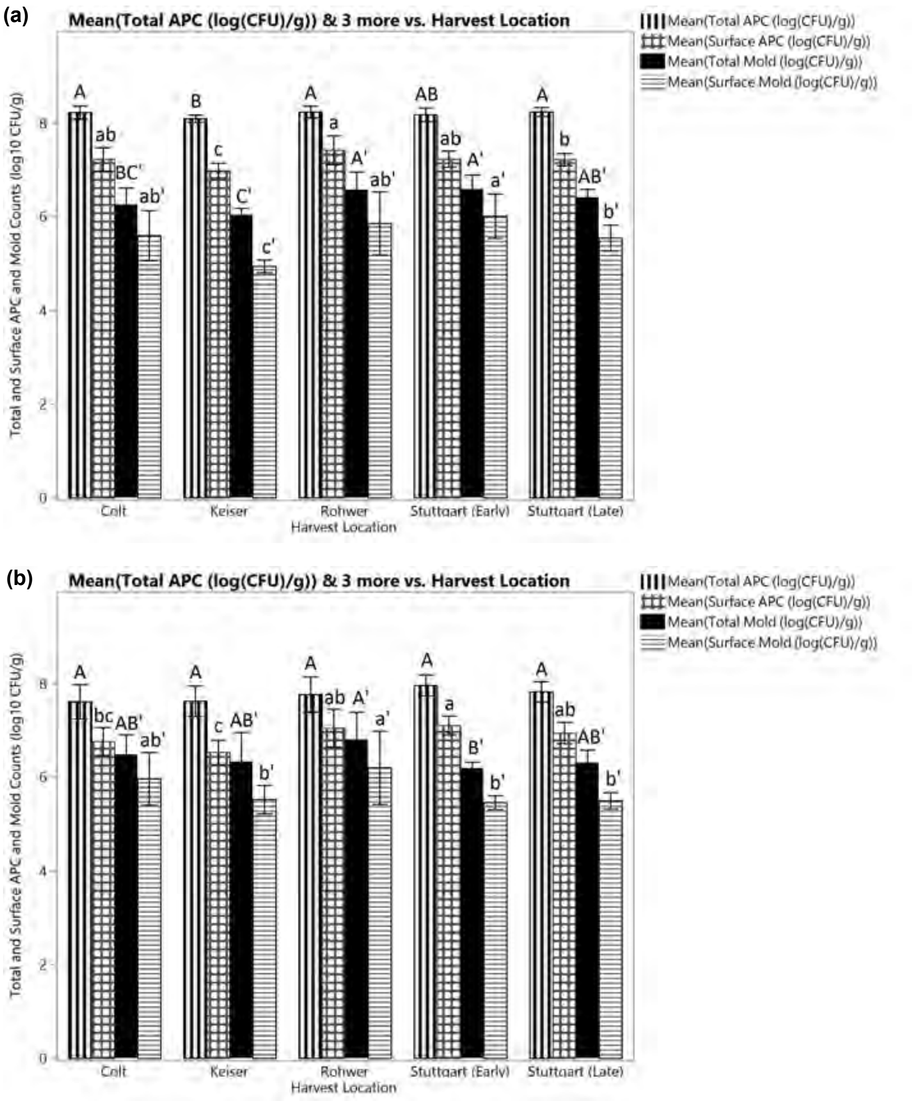


Fig. 1. Total and surface aerobic plate count (APC) (log CFU/g) and total mold counts (log CFU/g) on rice grown at four Arkansas locations (Stuttgart (Early and Late), Rohwer, Colt and Keiser). (a) represents data for 2013 harvested samples, and (b) represents data for 2014 harvested samples. Error bars show ± standard deviation (n = 90 (2013), n = 60 (2014)). Means with the same type of letters are not significantly different at α = 0.05; each set of total and surface APC and mold counts were analyzed separately.

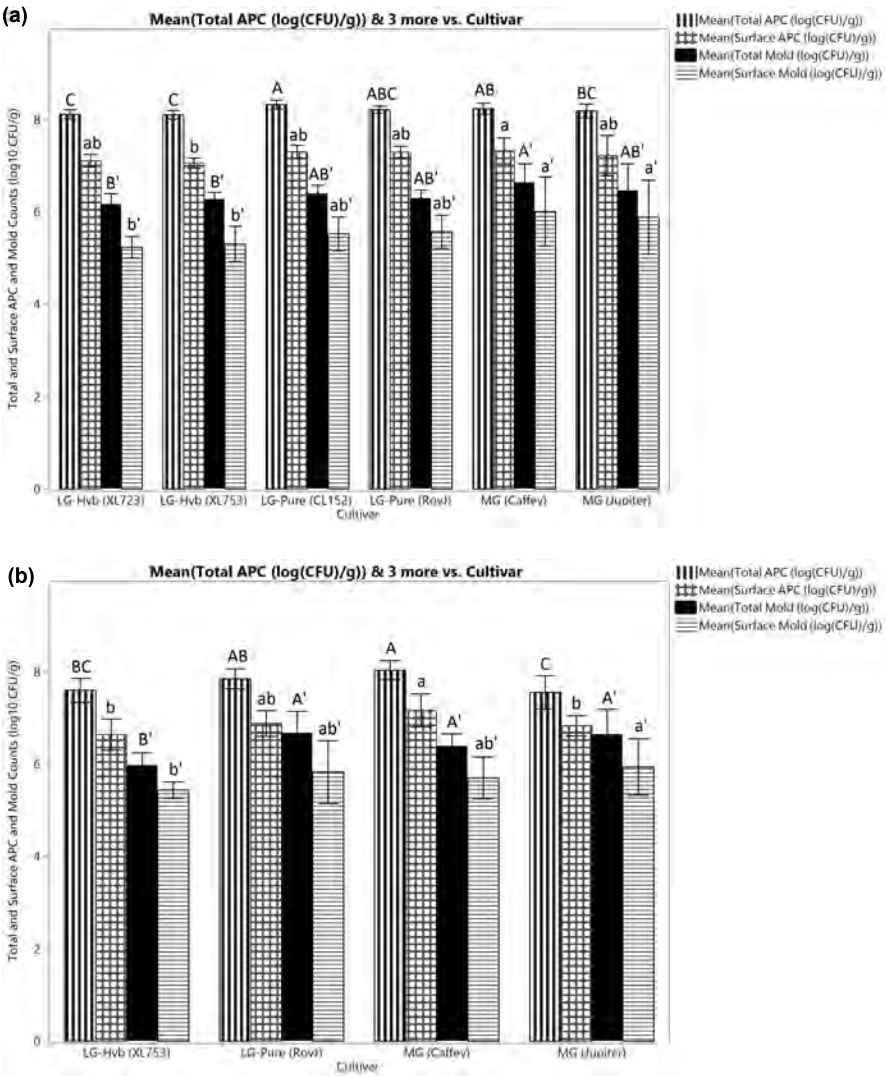


Fig. 2. Total and surface aerobic plate count (APC) (log CFU/g) and total and surface mold count (log CFU/g) on different types of rice: medium-grain (MG), long-grain pure-line (LG-Pure), and long-grain hybrid (LG-Hyb) rice cultivars. (a) represents data of 2013 harvested samples, and (b) represents data of 2014 harvested samples. Error bars show ± standard deviation (n = 90 (2013), n = 60 (2014)). Means with the same type of letters are not significantly different at α = 0.05; each set of total and surface APC and mold counts were analyzed separately.

A Comparison of Methods Used to Quantify Chalkiness of Head Rice

B.C. Grigg and T.J. Siebenmorgen

ABSTRACT

Chalkiness of rice impacts functionality, visual perception, and marketability. A study was initiated to compare chalkiness scores resulting from the current, manual Federal Grain Inspection Service (FGIS) method and newer, semi-automated, digital-imaging systems. Chalkiness of head rice was determined for one medium- and two long-grain cultivar lots using the FGIS method and two digital-imaging methods. For the least-chalky lot, the digital-imaging methods predicted similar chalkiness values to those of the FGIS method. As surface chalkiness increased, the digital-imaging methods indicated increasingly greater chalkiness than did the FGIS method. However, alternative reporting formats show promise in reconciling chalkiness scores of digital-imaging methods with those of the manual FGIS method.

INTRODUCTION

Chalky (opaque) rice kernels are characterized by loosely packed starch in the endosperm. Chalkiness can be caused by environmental stresses such as elevated nighttime air temperatures occurring during kernel development (Ambardekar et al., 2011; Lanning et al., 2011). Chalkiness of rice impacts marketability (McClung, 2013), milling quality (Lanning et al., 2011), and end-use functionality (Lisle et al., 2000). The United States standard for determination of chalk in rice defines chalky kernels as "whole or broken kernels of rice which are one-half or more chalky" (USDA-GIPSA-FGIS, 2014). This U.S. standard is relatively conservative when compared to visual appraisal of chalkiness on a kernel-area basis, and may not relate well to processing operations such as puffing.

Digital-imaging technologies have been developed to quantify chalk on a kernel-area basis. For several years, one such system (WinSEEDLE Pro 2005a, Regent Instruments Inc., Sainte-Foy, Quebec, Canada) has been used by various laboratories, and is reasoned to quantify chalkiness as perceived by a consumer's visual inspection. In addition to the Winseedle, another digital-imaging system (SeedCount SC5000TR, Next Instruments Pty Ltd., Condell Park, NSW, Australia) has recently been introduced. Working in a similar manner to the WinSEEDLE, the SeedCount quantifies chalky area of rice kernels, but differentiates between chalky and non-chalky area according to pre-established standards for U.S. and international markets. A study was conducted to compare chalkiness determination by the manual U.S. standard method with the semi-automated WinSEEDLE and SeedCount digital-imaging methods.

PROCEDURES

Harvested in 2012, one medium-grain (MG) cultivar lot, and two long-grain (LG) cultivar lots, were evaluated. The MG lot was harvested near Stuttgart, Ark., while the two LG lots (LG1 and LG2) were harvested near Keiser, Ark. All lots were cleaned with a dockage tester (XT4, Carter-Day, Minneapolis, Minn.), and conditioned (26 °C and 56% relative humidity) in a climate-controlled chamber (5580A, Parameter Generation & Control, Black Mountain, N.C.) to 12.0 ± 0.5% (wet basis) moisture content. Moisture content was determined using a moisture meter (AM5200, Perten Instruments, Hägersten, Sweden). After conditioning, lots were stored at 40 ± 2 °F, then equilibrated to room temperature for 24 h prior to use.

For each lot, four, 150-g samples of rough rice were dehulled using a laboratory sheller (THU 35B, Satake Corp., Hiroshima, Japan) with a clearance of 0.019 inch between the rollers. Each sample was milled (McGill No. 2, RAPSCO, Brookshire, Texas; equipped with a 3.3-lb weight on the lever arm, situated 6 inches from the milling chamber centerline) for a 30 s duration. Two of the milled samples (1 and 2) were submitted to the Federal Grain Inspection Service (USDA-GIPSA-FGIS), Stuttgart Field Office, Stuttgart, Ark., for determination of chalk according to the U.S standard (FGIS) method. For the FGIS method, chalk was determined for one 25 g subsample of each sample, of which each rice kernel was manually evaluated (Fig. 1). Individual kernels were scored as chalky if greater than 50% (by volume) of the kernel was chalky (USDA-GIPSA- FGIS, 2014). Chalkiness was calculated as the mass percentage of chalky kernels relative to the original subsample mass.

For the remaining two milled samples (3 and 4) of each lot, head rice (kernels at least 0.75 of their original length) was separated from broken kernels using a sizing device (61, Grain Machinery Manufacturing Corp., Miami, Fla.). In contrast with the FGIS method, chalkiness of head rice from each of these two samples was determined using semi-automated, digital-imaging systems (Fig. 1). The WinSEEDLE method consisted of randomly selecting duplicate 100-kernel subsamples of head rice kernels (200 kernels in total; approximately 4 g) from each of the two samples. Each of the 100-kernel subsamples was digitally scanned with the WinSEEDLE system in order to determine chalkiness, which was expressed on an area-percentage basis, the ratio of the chalky area to the entire, scanned area of the 100 kernels. Prior to chalk measurements, the WinSEEDLE system was configured to color-classify chalk by selecting and scanning a completely chalky kernel of head rice into the imaging system as a reference color for chalk.

The SeedCount method consisted of randomly selecting duplicate 500-kernel subsamples of head rice (1,000 kernels in total; approximately 20 g) from each of the two samples. Similar to the WinSEEDLE, the SeedCount employed a flat-bed scanner to create a digital image of rice kernels, from which the SeedCount system also quantified chalkiness as an area percentage. The SeedCount system was factory pre-calibrated to detect chalkiness. Prior to this study, sensitivity of the SeedCount method was adjusted, such that chalkiness results correlated well ($r = 0.985$) with those of the WinSEEDLE method.

Kernel-by-kernel data from the two digital-imaging systems also allowed for alternative scoring of chalkiness, as compared to the typical, area-percentage scores for each subsample. Thus, chalkiness from the WinSEEDLE and SeedCount methods was also reported as a number percentage of kernels exceeding either 25% or 50% chalky area per kernel.

RESULTS AND DISCUSSION

The FGIS method resulted in chalkiness of 1.4% for the MG lot (Fig. 2). In contrast, the WinSEEDLE and SeedCount methods resulted in area-percentage chalkiness scores of 3.8% and 3.7%, respectively. Alternately, number-percentage scoring for kernels with chalkiness greater than 25% of kernel area resulted in 5.1% and 5.2% for the WinSEEDLE and SeedCount methods, respectively. For kernels with chalkiness exceeding 50% of kernel area, number percentages were 1.6% and 2.2% for the WinSEEDLE and SeedCount methods, respectively, thus, closely approximating mass-percentage results of the FGIS method.

Chalkiness of the LG1 lot was determined to be 0.4%, 0.8%, and 1.1% by the FGIS, WinSEEDLE, and SeedCount methods, respectively (Fig. 3a); differences between methods were considerably less for this least-chalky lot than observed for the MG lot (Figs. 2 and 3a). For both digital-imaging methods, the number percentage of LG1 kernels with chalkiness exceeding 50% of kernel area closely approximated the chalkiness score of the FGIS method .

The FGIS method resulted in chalkiness of 1.4% for the LG2 lot (Fig. 3b); however, the WinSEEDLE and SeedCount methods indicated chalkiness of 11.7% and 7.9%, respectively, reflecting greater surface chalkiness. The number percentages of LG2 kernels with chalkiness exceeding 25% of kernel area were 17.3% and 13.6% for the WinSEEDLE and SeedCount methods, respectively. For this LG2 lot with the greatest chalkiness, number percentages of kernels with chalkiness exceeding 50% of kernel area more closely approximated those of the FGIS method, with 4.4% and 6.8% for the WinSEEDLE and SeedCount methods, respectively.

SIGNIFICANCE OF FINDINGS

These data illustrate the challenge in relating digitally-imaged chalkiness measurement to that of the current U.S. standard methodology. Chalkiness determined by the manual FGIS method remained relatively consistent across these three cultivar lots. The WinSEEDLE and SeedCount methods provided a rapid determination of rice chalkiness, with minimal training requirements. Using area-percentage based scoring of chalkiness, these digital-imaging methods reflected increasing surface chalkiness—a potential benefit when predicting visual impact of surface chalkiness, and when chalkiness of any sort impacts end-use processing. However, the digitally-imaged, area-based scoring of chalkiness did not always compare well with the standard FGIS method. Alternative, number-percentage based scoring available with the WinSEEDLE and SeedCount methods shows promise in reconciling digitally-imaged determination of chalkiness with that of the FGIS methodology.

ACKNOWLEDGMENTS

The authors acknowledge the Kellogg Company and the Arkansas Rice Research and Promotion Board for financial support. The authors also acknowledge technical support from the USDA-GIPSA-FGIS, Stuttgart Field Office, Stuttgart, Ark. The authors appreciate the contributions of technicians of the U of A Rice Processing Program, and of agronomic crews of the NEREC and RREC.

LITERATURE CITED

Ambardekar, A.A., T.J. Siebenmorgen, P.A. Counce, S.B. Lanning, and A. Mauromoustakos. 2011. Impact of field-scale nighttime air temperatures during kernel development on rice milling quality. Field Crops Res. 122(3):179-185.

Lanning, S.B., T.J. Siebenmorgen, P.A. Counce, A.A. Ambardekar, and A. Mauromoustakos. 2011. Extreme nighttime air temperatures in 2011 impact rice chalkiness and milling quality. Field Crops Res. 124(1):132-136.

Lisle, A.J., M. Martin, and M.A. Fitzgerald. 2000. Chalky and translucent rice grains differ in starch composition and structure and cooking properties. Cereal Chem. 77(5):627-632.

McClung, A. 2013. Report to the USA rice federation rice marketability and competitiveness task force: Quality assessment of rice samples produced in 2012. Arlington, Va: USA Rice Federation.

Saleh, M.I., J.-F. Meullenet, and T.J. Siebenmorgen. 2008. Development and validation of prediction models for rice surface lipid content and color parameters using near-infrared spectroscopy: A basis for predicting rice degree of milling. Cereal Chem. 85(6):787-791.

USDA-GIPSA-FGIS. United States Department of Agriculture Grain Inspectors, Packers, and Stockyards Administration Federal Grain Inspection Service. 2014. Rice Inspection Handbook. Last updated June 2014. Accessed 20 January 2015. Available at: http://www.gipsa.usda.gov/fgis/handbook/rice_inspec.aspx.

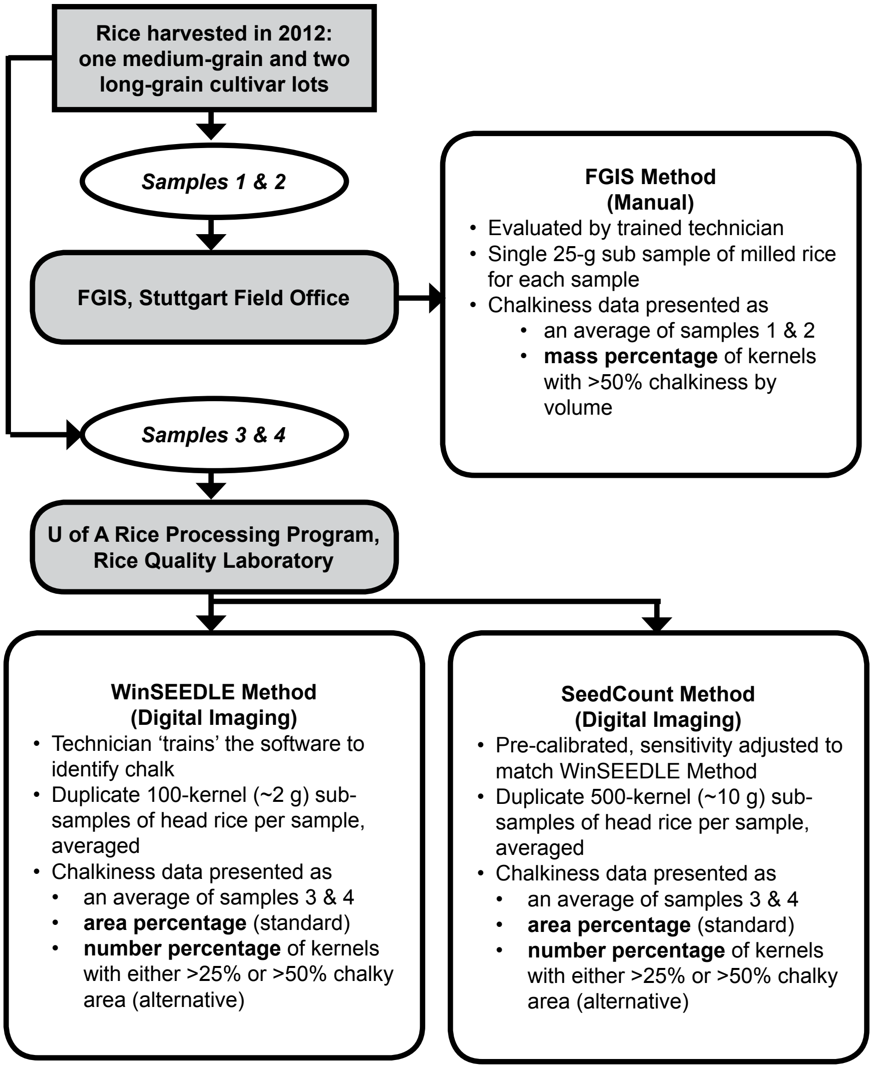


Fig. 1. Sample disposition and details of the manual U.S. standard Federal Grain Inspection Service (FGIS), WinSEEDLE, and SeedCount methods of chalk determination.

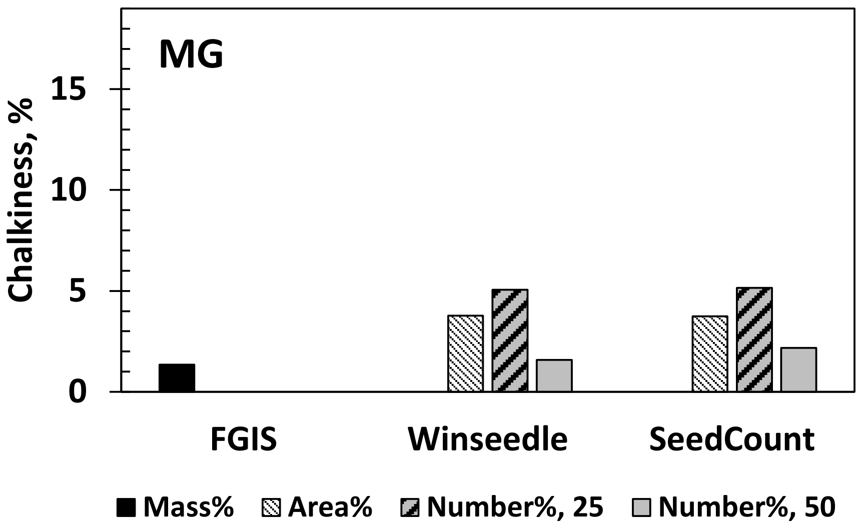


Fig. 2. Chalkiness of the medium-grain (MG) cultivar lot, as determined by the manual U.S. standard Federal Grain Inspection Service (FGIS), WinSEEDLE, and SeedCount methods. Data are reported as a mass-, area-, or number-percentage, dependent on the capabilities of each method. Number percentages represent the proportion of kernels exceeding either 25% or 50% chalky area per kernel.

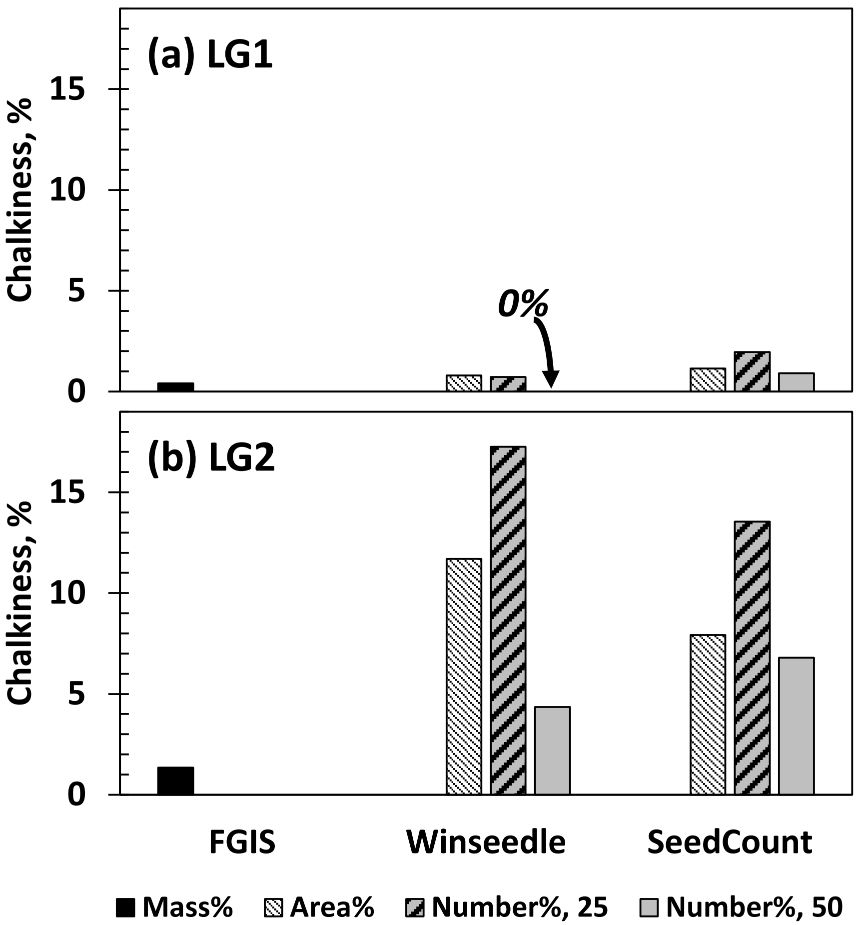


Fig. 3. Chalkiness of the two long-grain (LG) cultivar lots, (a) LG1 and (b) LG2, as determined by the manual U.S. standard Federal Grain Inspection Service (FGIS), WinSEEDLE, and SeedCount methods. Data are reported as a mass-, area-, or number-percentage, dependent on the capabilities of each method. Number percentages represent the proportion of kernels exceeding either 25% or 50% chalky area per kernel.

Functional Properties of Commingled Rice-Cultivar Lots

K.N. Haydon, N.N. Basutkar, T.J. Siebenmorgen, and Y-J. Wang

ABSTRACT

Commingling of rice cultivars commonly occurs during harvest, drying, and storage operations. As different cultivars often have different functional properties, there is a need to study the impact of commingling on these properties. Two long-grain, hybrid cultivars, Clearfield (CL) XL745 and CLXL729, and two long-grain, pure-line cultivars, CL151 and Wells, were used to prepare hybrid/pure-line, hybrid/hybrid, and pure-line/pure-line commingles in various proportions. Gelatinization and pasting properties, as indicators of functional performance, were measured for all individual lots and commingled samples. When two cultivar lots with different onset gelatinization temperatures (T_os) were commingled, the T_o of the commingled sample was similar to the T_o of that cultivar in the commingle with the lower T_o. Other gelatinization properties, as well as peak, breakdown, and final viscosities of commingled samples generally increased or decreased according to the mass percentages of the cultivars in the samples.

INTRODUCTION

Gelatinization and pasting properties of rice have a significant impact on end-use applications. These properties can differ among cultivars, impacting final product characteristics and process costs when manufacturing on an industrial scale (Juliano, 1998). Gelatinization is a process in which starch undergoes order-disorder transitions with the application of heat to kernels that have been soaked (Sivak and Preiss, 1998). Determining the temperature and energy required for gelatinization is therefore of particular importance to food processors who need to optimize cooking conditions and reduce process costs (Bao and Bergman, 2004). After becoming gelatinized, starch granules form a paste comprising a viscous material of starch granules and leached starch molecules. Thus, pasting properties are important indicators of cooking behavior of starch and final product quality (Manaois, 2009).

Commingling of rice cultivars commonly occurs during harvest, drying, and storage operations. As different cultivars often have different starch structure and milling properties (Siebenmorgen et al., 2006), commingling could impact functional properties, particularly when dissimilar cultivars are commingled.

PROCEDURES

The study was conducted using four long-grain cultivars, CLXL729 and CLXL745 (hybrids), and CL151 and Wells (pure-lines), each grown at various locations in Arkansas in both 2011 and 2012. The 2011 lots were selected to have high head rice yields (HRYs), while the 2012 lots were selected to have lower, in order to determine if commingling had a similar effect on rice of different levels of milling yield. All lots were cleaned using a dockage tester (Model XT4, Carter-Day Co., Minneapolis, Minn.) and conditioned to 12 ± 0.5% (wet basis) moisture content.

Samples from the cultivar lots were commingled in various ratios as presented in Table 1. To prepare for milling, 150-g rough rice samples were prepared for each commingling ratio. The masses of the individual cultivars in the commingled samples were 15/135 g, 38/112 g, 75/75 g, 112/38 g, and 135/15 g, respective to the 10:90, 25:75, 50:50, 75:25, and 90:10 commingling ratios. The individual lots of rough rice were first divided into a close approximation of the required quantities using a grain divider (Boerner Divider, Seedburo Equipment Co., Chicago, Ill.), weighed accurately to the above-mentioned values, and thoroughly mixed.

Each 150-g rough rice sample was first dehulled in a laboratory sheller (THU 35B, Satake, Hiroshima, Japan), then milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas), having a 1.5-kg mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Head rice was then separated from brokens using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, Fla.). Surface lipid content (SLC) of head rice was measured using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, Minn.). Individual-cultivar lots and commingled samples that had been milled for durations that produced a degree of milling (DOM) closest to 0.4% SLC, a typical industry standard, were used for measuring gelatinization and pasting properties.

Gelatinization properties of samples were measured using a differential scanning calorimeter (DSC) (Diamond, Perkin-Elmer, Shelton, Conn.). Samples of head rice (20 g) were ground using a cyclone mill (3010-30, UDY, Fort Collins, Colo.), equipped with a 100-mesh (0.5-mm) sieve. The DSC cycle comprised heating from 25 °C to 120 °C at a rate of 10 °C/min. Data output was in the form of a thermogram, in which the temperature at which gelatinization started (T_o), peaked (T_p), and concluded (T_c), as well as the energy required to gelatinize (ΔH), were determined by DSC system software (Pyris Data Analysis, Perkin-Elmer, Shelton, Conn.).

Pasting properties of rice flour were measured using a Rapid Viscoanalyser (RVA) (model 4, Newport Scientific, Warriewood, NSW, Australia). Exact amounts of flour and deionized water were obtained using RVA software (Thermocline for Windows, v.2.0, Newport Scientific, Warriewood, NSW, Australia), and mixed in a provided aluminum canister (Perten Instruments, Springfield, Ill.). The canister and paddle were then inserted into the RVA. The pasting cycle comprised holding the paste at 50 °C for 1.5 min, heating to 95 °C at 12.2 °C/min, holding at 95° C for 2 min, cooling to 50 °C at 12.2 °C/min, and finally holding at 50 °C for 1.5 min. The pasting properties studied included peak, breakdown, and final viscosities, where breakdown viscosity is the difference between peak viscosity and trough viscosity (minimum viscosity of the paste after peak viscosity is reached). Analysis of variance ($\alpha = 0.05$) and comparison of means using Tukey's Honestly Significant Difference (HSD) test were performed using statistical software JMP Pro v. 10 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

The 2011 samples milled for 30 s and the 2012 samples milled for 20 s were used to study gelatinization and pasting properties because their respective surface lipid contents (SLCs) were closest to 0.4%.

When there was no difference in the T_os of the individual cultivars in a commingle, as for example in the 2011 hybrid/pure-line commingle (Table 2), there was no difference in the T_os of the commingled samples of the two cultivars. In the 2012 hybrid/pure-line commingle, the T_os of the commingled samples were similar to the T_o of CL151, the cultivar with the lower T_o in the pair. This trend of the cultivar with the lower T_o determining the T_o of the commingled sample essentially held true for the 2012 H/H commingle and the pure-line/pure-line commingles from both years, as shown in Table 3. These trends suggest that regardless of being heated in a pure-line cultivar or commingled sample, starch granules will start gelatinizing at the same temperature, so that the cultivar with the lower T_o individually sets the T_o for the commingle. Chemical and structural properties should not be affected by a simple commingling of two cultivars.

When there were no significant differences between the T_ps and T_cs of two individual cultivars, there were no observed differences for the T_ps and T_cs of the commingled samples (Tables 2 and 3). When the individual T_ps and T_cs of the cultivars being commingled were different, however, the T_ps and T_cs of the commingled samples typically varied according to the mass percentages of the cultivars in the samples. There were no differences in the ΔH values of any commingled sample sets, except in the 2012 pure-line/pure-line commingled samples, where ΔH values proportionately increased with the associated increase in the percentage of CL151 in the samples (Table 3).

Peak, breakdown, and final viscosities of all individual-cultivar lots and commingled samples are presented in Figs. 1, 2, and 3, respectively. For all three viscosity parameters, the viscosities of the commingled samples were dependent on the individual-cultivar viscosities. When viscosities of the two individual cultivars were not statistically different, neither were the viscosities of the commingles, in any proportion. However, when viscosities of the two individual cultivars were different, the viscosities of the commingles increased or decreased according to the proportions of the two cultivars.

These consistent trends in viscosity properties indicate that commingled samples retained the pasting properties of the individual-cultivar lots used for commingling, i.e., if any of the aforementioned viscosities of the individual-cultivar lots used in a commingle were different, then the respective viscosities of the commingled samples either increased or decreased proportionately with the associated mass increase in the percentage of a given cultivar in the commingle.

SIGNIFICANCE OF FINDINGS

Commingling of cultivar lots did not adversely impact pasting properties as peak, breakdown, and final viscosities of commingled samples either increased or decreased proportionately with the associated increase in the mass percentage of a given cultivar in the commingled samples. Similarly, when the T_p, T_c, and ΔH values of the two cultivars being commingled were different, the T_p, T_c, and ΔH values of commingled samples varied according to the mass percentages of the cultivars in the samples. Commingling may indeed have an impact on the onset temperature of gelatinization, as starch granules in a commingled sample with the least T_o will determine the T_o of the commingled sample. These findings indicate that starch granules of a particular cultivar retain their inherent properties after commingling, resulting in deducible gelatinization and pasting properties for commingled samples, particularly for the crucially important parameter, T_o.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the corporate sponsors of the University of Arkansas System Division of Agriculture's Rice Processing Program, and the Rice Processing Program staff who assisted with data collection. The authors appreciate the assistance of the agronomic crews led by Donna Frizzell, Eddie Castaneda, Mike Duren and Shawn Clark in conducting this research.

LITERATURE CITED

Bao, J. and Bergman, C.J. 2004. The functionality of rice starch. pp. 258-294. *In:* Starch in food structure, function and applications. Boca Raton: Woodhead Publishing Ltd. and CRC Press LLC.

Juliano, B.O. 1998. Varietal impact on rice quality. Cereal Foods World 43(4):207.

Manaois, R.V. 2009. Modification of rice starch properties by addition of amino acids at various pH levels. Master's Thesis. Louisiana State University: U.S.

Siebenmorgen, T.J., A.L. Matsler, and C.F. Earp. 2006. Milling characteristics of rice cultivars and hybrids. Cereal Chem. 83(2):169-172.

Sivak, M.N. and J. Preiss. 1998. Industrial Applications of Starch. Advances in Food and Nutrition Res. 41:163-170.

Table 1. Experimental design for commingling samples from four cultivar lots harvested in 2011 and again in 2012.

Commingle	Cultivar-lot type	Commingling ratios
CLXL745/CL151	hybrid/pure-line	0:100, 10:90, 25:75, 50:50, 75:25, 90:10, 100:0
CLXL745/CLXL729	hybrid/hybrid	0:100, 25:75, 50:50, 75:25, 100:0
Wells/CL151	pure-line/pure-line	0:100, 25:75, 50:50, 75:25, 100:0

Table 2. Onset (T_o), peak (T_p), and conclusion (T_c) gelatinization temperatures, and gelatinization enthalpies (ΔH), of the CLXL745/CL151 (hybrid/pure-line) commingled samples in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.

Year	Commingling ratio	Gelatinization temperatures (°C)			
		T_o	T_p	T_c	ΔH (kJ/g)
2011	0:100	72.7 ab[†]	78.1 c	83.5 e	9.3 a
	10:90	72.0 ab	78.4 c	84.8 de	9.4 a
	25:75	71.9 b	78.6 bc	85.1 cd	10.1 a
	50:50	72.2 ab	78.7 bc	86.4 bc	9.3 a
	75:25	72.1 ab	79.3 ab	87.4 ab	10.5 a
	90:10	73.0 ab	79.8 a	88.7 a	9.5 a
	100:0	73.1 a	79.5 ab	87.2 ab	9.7 a
2012	0:100	75.6 B	80.7 C	87.2 D	11.0 A
	10:90	75.8 B	81.0 BC	87.5 CD	10.1 A
	25:75	75.7 B	80.6 C	87.7 BCD	10.7 A
	50:50	75.7 B	80.8 BC	88.6 ABC	11.2 A
	75:25	75.9 B	81.4 ABC	89.4 A	11.2 A
	90:10	76.2 AB	81.6 AB	89.0 AB	10.1 A
	100:0	76.8 A	82.0 A	89.4 A	10.9 A

[†] Statistical differences in means (four replicates) of T_o, T_p, T_c, and ΔH, in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance.

Table 3. Onset (T_o), peak (T_p), and conclusion (T_c) gelatinization temperatures, and gelatinization enthalpies (ΔH) of the CLXL745/CLXL729 (hybrid/hybrid) and Wells/CL151 (pure-line/pure-line) commingled samples in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.

Commingle	Year	Commingling ratio	Gelatinization temperatures T_o	T_p	T_c	ΔH (kJ/g)
			---------------(°C)---------------			
CLXL745/ CLXL729	2011	0:100	72.5 ab[†]	78.5 b	86.8 b	10.2 a
		25:75	72.0 b	78.6 b	87.4 ab	10.4 a
		50:50	72.5 ab	79.5 a	87.8 a	10.0 a
		75:25	72.0 b	79.3 ab	87.2 ab	9.6 a
		100:0	73.1 a	79.5 a	87.2 ab	9.7 a
	2012	0:100	77.6 A	82.6 A	90.0 A	11.4 A
		25:75	76.8 B	81.8 A	89.7 A	12.0 A
		50:50	76.8 B	82.3 A	89.9 A	11.9 A
		75:25	77.1 AB	82.1 A	90.2 A	11.3 A
		100:0	76.8 B	82.0 A	89.4 A	10.9 A
Wells/ CL151	2011	0:100	72.7 c	78.1 b	83.5 c	9.3 a
		25:75	72.7 c	78.5 b	84.5 bc	9.0 a
		50:50	73.2 c	78.8 b	84.9 abc	8.5 a
		75:25	74.8 b	80.1 a	86.5 ab	9.8 a
		100:0	76.3 a	80.8 a	86.8 a	9.1 a
	2012	0:100	75.6 A	80.7 A	87.2 A	11.0 A
		25:75	75.5 AB	81.1 A	88.0 A	11.5 A
		50:50	75.3 AB	80.6 A	87.1 A	10.5 AB
		75:25	75.1 AB	80.6 A	87.7 A	10.5 AB
		100:0	74.8 B	80.5 A	87.7 A	9.6 B

[†] Statistical differences in means (four replicates) of T_o, T_p, T_c, and ΔH, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance.

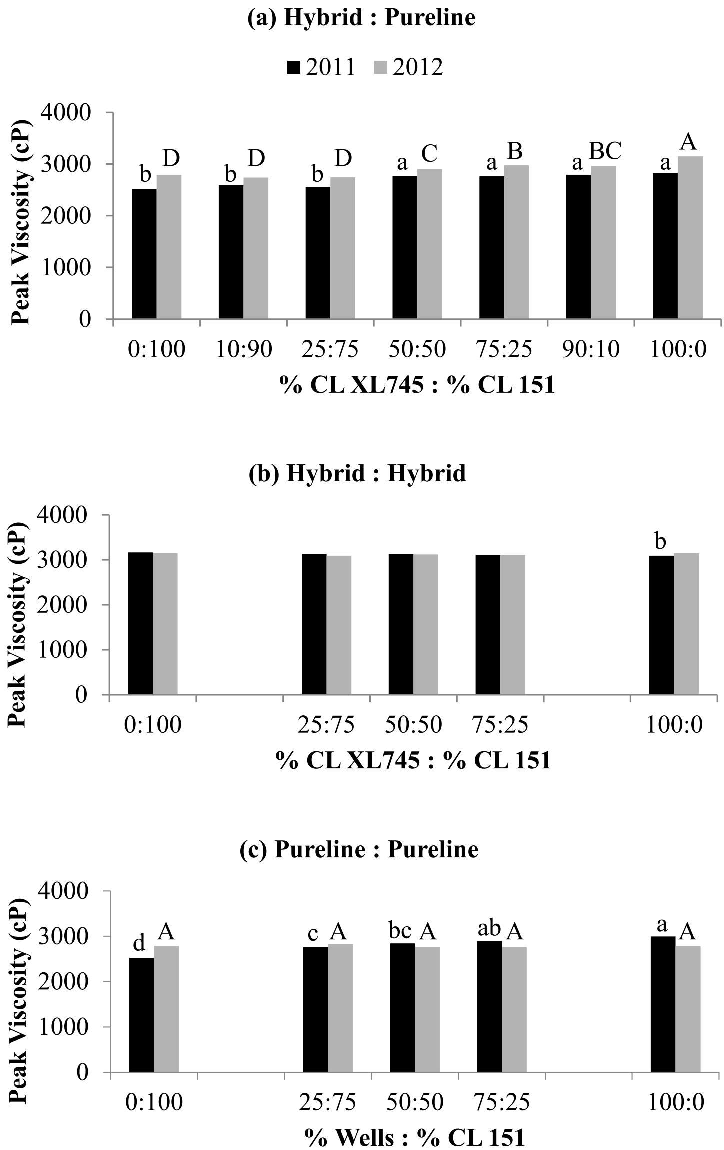


Fig. 1. Peak viscosities (means of four replicates) of the CLXL745/CL151 (a), CLXL745/CLXL729 (b), and Wells/CL151 (c) commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means of peak viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance.

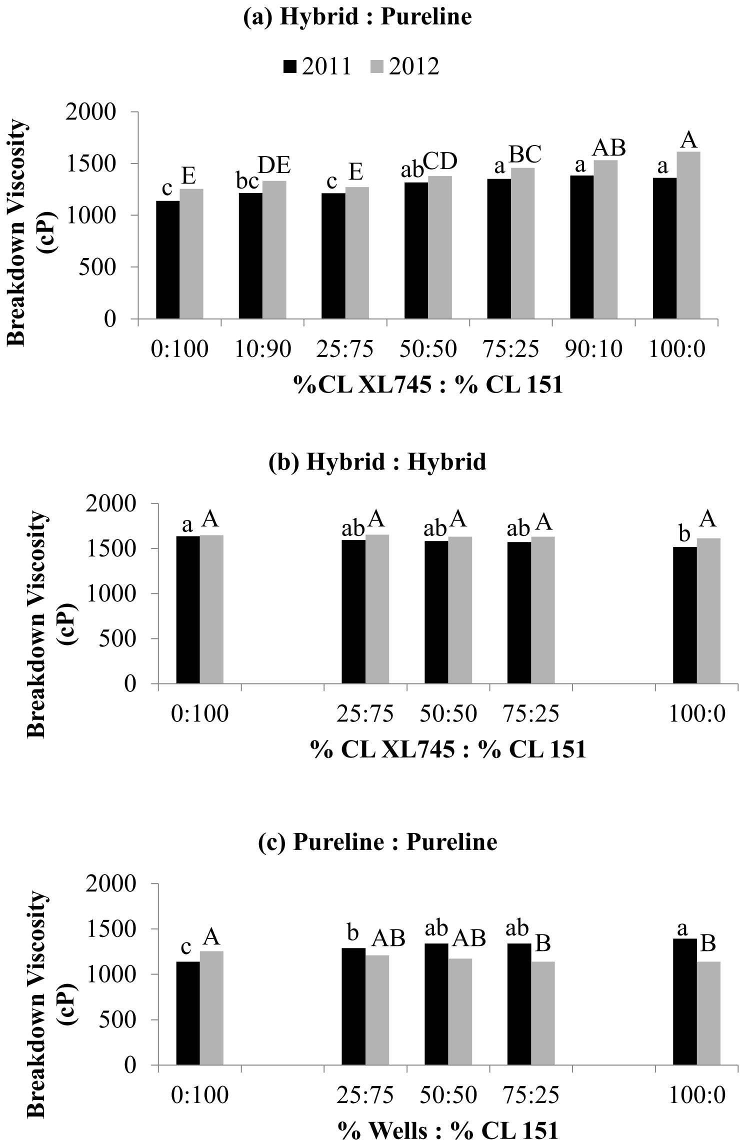


Fig. 2. Breakdown viscosities (means of four replicates) of the CLXL745/CL151 (a), CLXL745/CLXL729 (b), and Wells/CL151 (c) commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means of breakdown viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance.

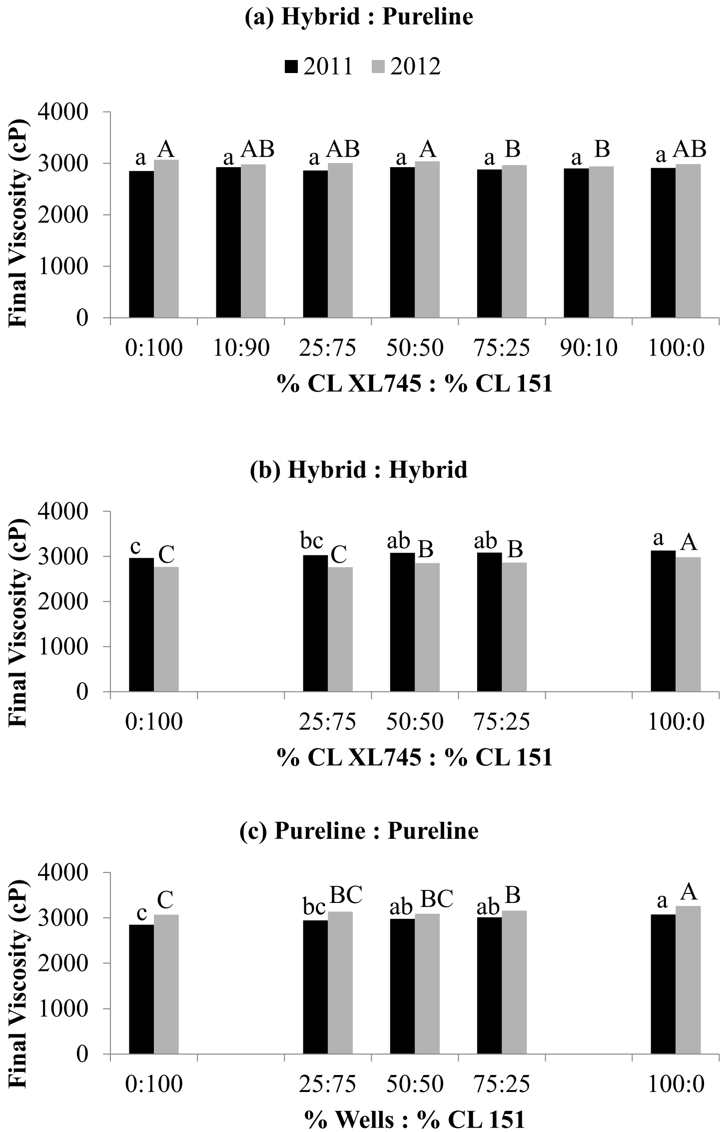


Fig. 3. Final viscosities (means of four replicates) of the CLXL745/CL 51 (a), CLXL745/CLXL729 (b), and Wells/CL151 (c) commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means of final viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance.

Physical and Functional Characteristics of Broken Rice Kernels Created by Rapid Moisture Adsorption

S. Mukhopadhyay and T.J. Siebenmorgen

ABSTRACT

Fissuring caused by rapid moisture adsorption generates appreciable amounts of broken kernels on subsequent milling, thereby reducing the economic value of rice. This study investigated how rapid moisture adsorption affects the extent of kernel fissuring in rice lots, as well as the physical and functional characteristics of broken kernels that result from milling such lots. Pure-line, long-grain cultivar Roy J was conditioned to 9% and 12% initial moisture content (IMC) levels, soaked in water at 30 °C (86 °F) for 2 h, gently re-dried to 12.0% moisture content (MC), and then milled to a surface lipid content of 0.4%. Milled rice yield, head rice yield, number-percentage of fissured kernels, and number of fissures/kernel were determined. Physical and functional properties of the broken kernels were also determined. Results showed that as IMC prior to rewetting decreased, the extent of fissuring increased, and hence, subsequent breakage increased. Additionally, with decreasing IMC, the number of fissures/kernel increased, leading to the generation of greater amounts of small brokens. The functional properties of the flour produced from small brokens were significantly different from the functional properties of the flour produced from large brokens. However, the functional properties of the flour produced from medium-sized brokens were not significantly different from those of the flour produced from either the small or large brokens.

INTRODUCTION

Fissuring induced by rapid moisture adsorption in low-moisture content (MC) rice causes breakage and thus reduces milling yields considerably. Appreciable amounts of broken kernels of various sizes are generated during milling of such rice lots. The

United States Department of Agriculture classifies the largest, intermediate, and smallest broken kernels as second heads, screenings, and brewers, respectively (USDA, 2007). These brokens are often ground to produce rice flour, and are also used as a pet-food ingredient. In the United States, the demand for rice flour has recently increased, since rice is a major ingredient in gluten-free diets/formulations (Gallagher et al., 2003). The rapid growth in rice use in the pet-food industry has also contributed to the steady increase in the demand for brokens.

Fissuring due to moisture adsorption is a common problem faced by rice producers, primarily due to logistical harvesting considerations. Many researchers (Stahel, 1935; Kunze and Choudhury, 1972; Jindal and Siebenmorgen, 1986) have reported that fissuring generally occurred when rice kernels at or below 13% to 14% bulk initial MC (IMC, wet basis) rapidly adsorbed moisture from the environment. Mukhopadhyay and Siebenmorgen (2012) recommended that long- and medium-grain rice cultivars grown in the mid-South be harvested at MCs > 15% to avoid the risk of head rice yield (HRY) reduction due to rapid rewetting and resultant fissuring.

While several studies have addressed the impact of rapid moisture adsorption on milling yields, no research was found that investigated the impact of this phenomenon on the physical and functional characteristics of the broken kernels generated from rice lots that had been exposed to different levels of moisture adsorption. Thus, the objectives of this study were to evaluate the impacts of moisture adsorption on the extent of fissuring, as well as the particle-size distribution and functionality of the resultant broken kernels. Finally, the number of fissures/kernel at the rough-rice stage was correlated to the particle-size distribution of broken kernels produced during milling, the hypothesis being that kernels with multiple fissures break into smaller pieces during the milling process and thus alter the relative distribution of brokens into different classification grades.

PROCEDURES

Figure 1 shows the process flowchart for this study. Pure-line, long-grain cultivar Roy J was combine-harvested at 19.1% MC (wet basis) from Osceola, Ark., cleaned using a grain cleaner (MCI Kicker Grain Tester, Mid-Continent Industries Inc., Newton, Kan.), and stored in sealed containers at 4 °C (39 °F) until use. A 6-kg (13.2-lb) bulk lot was equilibrated at room temperature for 24 h before conducting experiments. This bulk lot was divided into three sublots (2 kg each), spread on screen-bottomed trays, and placed in a conditioning chamber where temperature and relative humidity were controlled by an air-control unit (Model 5580A, Parameter Generation & Control Inc., Black Mountain, N.C.) to condition two sublots to 12% IMC and the remaining sublot to 9% IMC. Subsequently, one of the 12%-IMC sublots ("12%-IMCcontrol"; Fig. 1) was used as a control, as well as to conduct a preliminary milling investigation as described below; whereas, the other two sublots (9%- and 12%-IMC) were rewetted in a water bath to induce fissures due to rapid moisture adsorption. For all three sublots, MC was determined by drying 15-g subsamples in a convection oven (Model 1370FM, Shellblue, Sheldon Mfg. Inc., Cornelius, Ore.) at 130 °C for 24 h (Jindal and Siebenmorgen, 1987).

Enumeration of Fissures and Determination of Milling Yields

The "9%-IMCrewetted" and "12%-IMCrewetted" sublots were placed in vinyl screen cloth bags and soaked for 2 h in a water bath (Model 280, Precision Scientific, Winchester, Va.) with the water held at 30 °C (86 °F) to induce fissures due to rapid rewetting (Mukhopadhyay and Siebenmorgen, 2012). The bags were then drained for 0.5 h, allowed to air-dry for 1 h, and slowly redried to 12% MC inside the above-mentioned conditioning chamber. From each of the three sublots, triplicate subsamples of 300 rough-rice kernels were randomly selected, manually dehulled, and examined visually for fissures using a fissure-inspection box (Model TX-200, Grainscope, Kett Electric Laboratory, Tokyo, Japan). Fissured kernels were enumerated and expressed as a number-percentage of the 300 rough-rice kernels. The number of fissures/kernel was also determined.

Additionally, triplicate, 150-g subsamples were dehulled and milled to a surface lipid content (SLC) of 0.4% to determine milling yields. In order to mill the three sublots to the desired SLC level, a preliminary milling investigation was conducted using the 12%-IMCcontrol sublot; ten 150-g subsamples (5 milling durations × 2 repetitions) were dehulled using a laboratory huller (Model THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) with a clearance of 0.048 cm (0.019 in.) between the rollers. These subsamples were milled for 10, 15, 20, 30, or 40 s using a laboratory mill (McGill No.2, Rapsco, Brookshire, Texas) with a 1.5-kg (3.3-lb) mass placed on the lever arm 15 cm (6 in.) from the center of the milling chamber. Then, the milled subsamples were passed through a sizing device (Model 61, Grain Machinery Manufacturing Co., Miami, Fla.), which separated head rice from broken kernels. Head rice SLC was determined by scanning 50 g of head rice using a near-infrared-reflectance spectrophotometer (Model DA7200, Perten Instruments, Hägersten, Sweden) (Saleh et al., 2008) and SLC was plotted as a function of milling duration. From the resulting curve, the milling duration necessary to reach an SLC of 0.4% was recorded and this duration (24 s in this case) was used to mill subsequent 150-g subsamples from the three sublots.

Physical and Functional Characteristics of Broken Kernels

The standard procedure for conducting a particle-size distribution analysis comprises a sieving procedure with at least a 100-g (0.22-lb) sample, although lesser sample amounts may be used if necessary (ASAE, 2003). The amount of broken kernels generated from the 9%-IMCrewetted sublot was sufficient to charge a sieve-set following the standard recommendation. However, additional subsamples of the 12%-IMCrewetted sublot had to be milled and separated to yield the suggested 100 g of broken kernels to charge the sieve-set. The 12%-IMCcontrol sublot generated negligible amounts of brokens; hence, sieve and viscosity-profile analyses were not conducted for this sublot (Fig. 1). A sieve shaker (RO-TAP, Model RX-29, Mentor, Ohio) with U.S. sieve numbers 10, 12, and 20, having square-openings of 2.00 mm (0.079 in.), 1.68 mm (0.066 in.), and 0.841 mm (0.033 in.), respectively, was used; brokens were shaken for 15 min. The sieves distributed the broken kernels into three fractions: "large" (retained on the 2-mm sieve), "medium" (passed through the 2-mm sieve but retained on the 1.68-mm sieve), and “small” (passed through the 1.68-mm sieve but retained on the 0.841-mm sieve). Since a negligible mass of broken kernels (<1 g) passed through the 0.841-mm sieve, only the mass of brokens retained on that sieve was taken into account.

After the size-fractioning step, ~7 g of broken kernels was selected from each of the large-, medium-, and small-broken kernel fractions, and ground into flour using a cyclone sample mill (Udy Corp., Fort Collins, Colo.) equipped with a 0.5-mm (0.02-in.) screen. Moisture contents were determined by drying ~2 g of flour in the convection oven at 130 °C for 1 h (Juliano et al., 1985) prior to calculation of the exact masses of flour and water required to analyze viscosity profiles using a rapid visco-analyzer (Model RVA-4 Series, Newport Scientific Pvt. Ltd., Warriewood, NSW, Australia) per AACC Method 61-02 (AACC, 2000).

Data Analyses

All statistical analyses were performed using JMP® Pro software v.11.0.0 (SAS Institute, Inc., Cary, N.C.). Analysis of variance (ANOVA, $\alpha = 0.05$) was conducted and means separated using the Fisher’s least significant difference test (LSD, $P = 0.05$).

RESULTS AND DISCUSSION

Enumeration of Fissures and Determination of Milling Yields

Figure 2 shows the number-percentage of fissured kernels, milled rice yield (MRY), and HRY for the 9%- and 12%-IMCrewetted sublots, along with the control (12%-IMCcontrol) sublot. The rapid moisture-adsorption treatment through soaking produced dramatic fissuring. Basically all the kernels in the 9%-IMCrewetted sublot developed fissures, whereas, only 29% of kernels from the 12%-IMCrewetted sublot fissured; both were significantly greater than the number-percentage of fissured kernels in the control sublot (only 0.2%). The extent of fissuring is reflected in the milling yields, in that the 12%-IMCrewetted sublot had a significantly lesser MRY, as well as HRY, than the control. The 9%-IMCrewetted sublot had a significantly lesser MRY compared to both the control and the 12%-IMCrewetted sublots. The decrease in MRY for the rewetted sublots suggest that with severe fissuring and breakage, some endosperm leaves with the bran stream during milling, thus decreasing the total mass of rice produced through milling. The severe fissuring incurred in the 9%-IMCrewetted sublot resulted in a HRY near 0%.

Figure 3 shows the frequency distribution of fissures/kernel for the 9%- and 12%-IMCrewetted sublots. In general, brown rice kernels from the 12%-IMCrewetted sublot had fewer fissures/kernel compared to those from the 9%-IMCrewetted sublot. Most of the fissured kernels (96%) from the 9%-IMCrewetted sublot had multiple fissures/kernel, with only 0.2% and 3.4% of the kernels having 1 and 2 fissures/kernel, respectively. However, for the 12%-IMCrewetted sublot, only 2.2% of the kernels had 3, 4, or 6 fissures/kernel; whereas 19.9% and 6.8% of the kernels had 1 and 2 fissures/kernel, respectively. These findings indicate that the lesser the IMC of the rice prior to rewetting, not only was there more fissuring and consequent breakage in kernels, but also the number of fissures incurred per kernel was greater, as is evident from the frequency distributions for the two rewetted sublots in Fig. 3.

Physical and Functional Characteristics of Broken Kernels

As seen in Fig. 3, 96% of the kernels from the 9%-IMCrewetted sublot had 3 to 7 fissures/kernel compared to only 2.2% of the kernels from the 12%-IMCrewetted sublot. Thus, it was expected that more kernels from the 9%-IMCrewetted sublot would break into smaller pieces during milling as compared to those in the 12%-IMCrewetted sublot. Figure 4 confirmed this; the 9%-IMCrewetted sublot generated a significantly greater mass percentage of small brokens as compared to the 12%-IMCrewetted sublot. Figure 4 also shows that the mass percentage of medium brokens was significantly greater in the 12%-IMCrewetted sublot than that in the 9%-IMCrewetted sublot. These results indicate, however, that although there were dramatic differences in the number of fissures/kernel in the two rewetted sublots (Fig. 3), this was not entirely reflected in the differences in size distribution of the resultant broken kernels from each sublot (Fig. 4).

Peak viscosity, final viscosity, and setback of the large-, medium-, and small-broken kernel fractions were not affected by differences in IMC levels prior to rewetting. Thus, viscosity data of brokens from the 9%- and 12%-IMCrewetted sublots were pooled and differences in functional properties were analyzed based on the size fractions of brokens. Figure 5a shows that large brokens had a significantly greater peak viscosity than that of the small brokens. However, peak viscosity of medium brokens was not significantly different from either small or large brokens. The small brokens had a significantly greater final viscosity compared to both large and medium brokens; but, the final viscosity of medium and large brokens were not significantly different (Fig. 5b). Figure 5c shows that the small brokens had the maximum setback, significantly greater than that of large brokens. As observed for peak viscosity, setback of medium brokens was not significantly different from either small or large brokens. In general, although there were differences in functional properties of the flour produced from small and large brokens, the functional properties of flour produced from medium brokens was not tremendously different from that of either small or large brokens.

SIGNIFICANCE OF FINDINGS

This study showed that the lesser the IMC of rice before rewetting, the greater the number of kernels that developed fissures, and the greater the number of fissures induced per kernel. Further, kernels with multiple fissures broke into smaller pieces during milling, and thus, generated a greater mass percentage of small brokens. Additionally, the functional properties of broken rice kernels were impacted by the broken-size fractions.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture's Rice Processing Program

Industry Alliance Group for the financial support of this project. The authors also acknowledge the efforts of Daniela Bruna Lopes Dos Santos for collection of data pertaining to this study.

LITERATURE CITED

AACC International. 2000. Approved Methods of Analysis. 10th Ed. Method 61-02: Determination of the pasting properties of rice with the rapid visco-analyzer. *In:* Approved Methods of the American Association of Cereal Chemists, 10th Ed., American Association of Cereal Chemists, St. Paul, Minn.

ASAE, 2003. ANSI/ASAE Standard S319.3 FEB 03: Method of determining and expressing fineness of feed materials by sieving. American Society of Agricultural Engineers, St. Joseph, Mich.

Gallagher, E., T.R. Gormley, and E.K. Arendt. 2003. Crust and crumb characteristics of gluten-free breads. J. Food Eng. 56(2-3):153-161.

Jindal, V.K. and T.J. Siebenmorgen. 1986. Effects of moisture adsorption on the head rice yields of long-grain rough rice. Trans. of the ASAE. 29(6):1767-1771.

Jindal, V.K. and T.J. Siebenmorgen. 1987. Effects of oven drying temperature and drying time on rough rice moisture-content determination. Trans. of the ASAE. 30(4):1185-1192.

Juliano, B.O., C.M. Perez, E.P. Alyoshin, V.B. Romanov, M.M. Bean, K.D. Nishita, A.B. Blakeney, L.A. Welsh, L.L. Delgado, A.W. El Baya, G. Fossati, N. Kkong-seree, F.B. Mendes, S. Brillante, H. Suzuki, M. Tada, and B.D. Webb. 1985. Co-operation test on amylograph of milled rice flour for pasting viscosity and starch gelatinization temperature. Starch. 37(2):40-50.

Kunze, O.R. and M.S.U. Choudhury. 1972. Moisture adsorption related to tensile strength of rice. Cereal Chem. 49(6):684-696.

Mukhopadhyay, S. and T.J. Siebenmorgen. 2012. Impact of rapid moisture adsorption on milling yields. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B R Wells Rice Research Studies, 2011. University of Arkansas Agricultural Experiment Station Research Series. 609:338-344. Fayetteville, Ark.

Saleh, M.I., J.-F. Meullenet, and T.J. Siebenmorgen. 2008. Development and validation of prediction models for rice surface lipid content and color parameters using near-infrared spectroscopy: a basis for predicting rice degree of milling. Cereal Chem. 85(6):787-791.

Stahel, G. 1935. Breaking of rice in milling in relation to the condition of the paddy. Tropical Agriculture. 10(2):267-271.

USDA. 2007. Rice Market News, Agricultural Marketing Service, U.S. Department of Agriculture. Accessed on 1 January 2015. Available at: http://www.ams.usda.gov/LSMNpubs/PDF_Weekly/rice.pdf

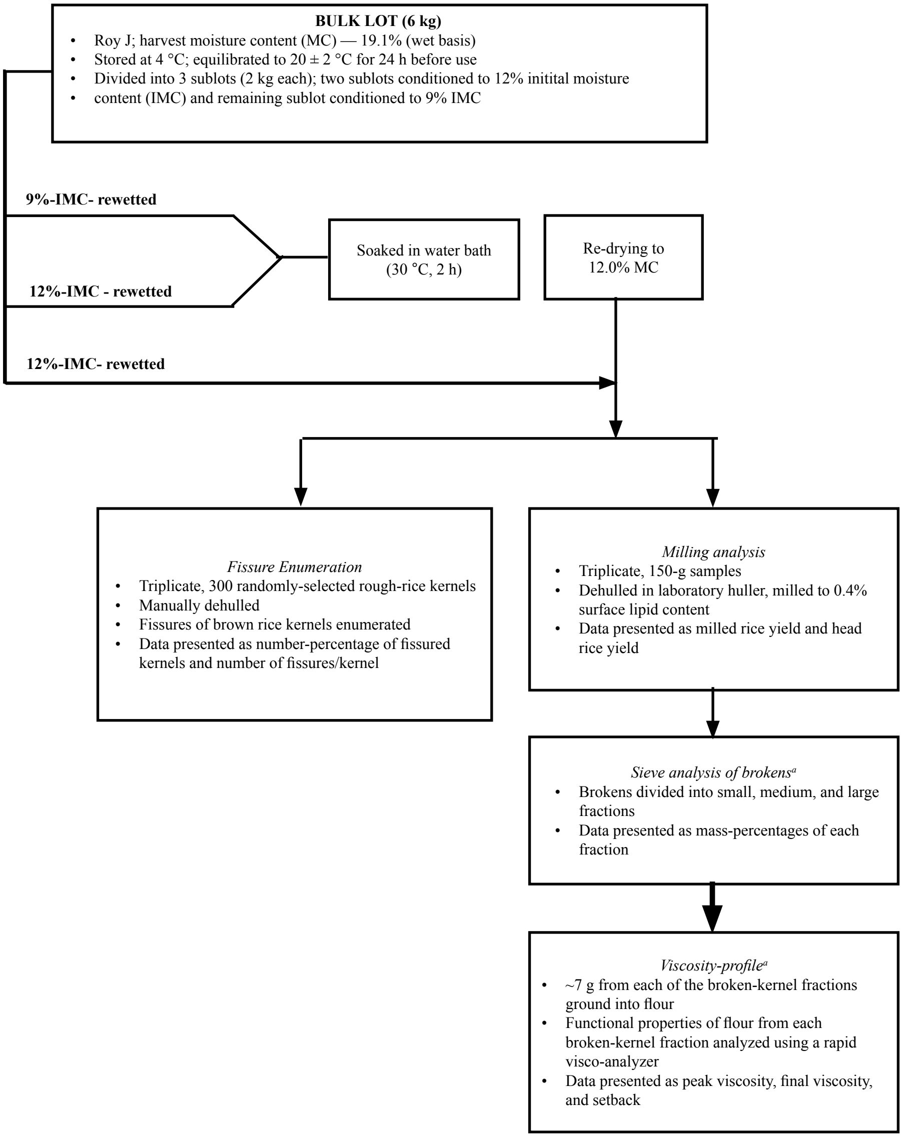


Fig. 1. Process flowchart for the experiment.
[a] Not analyzed for the 12%-IMC-control sublot owing to insufficient sample sizes.

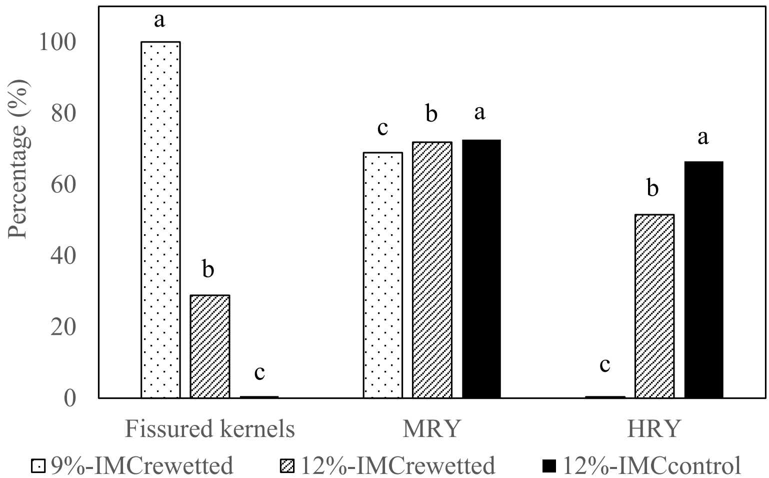


Fig. 2. Milled rice yield (MRY), head rice yield (HRY), and fissured kernels for cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. The control was gently dried from 19.1% harvest MC to 12% MC and milled. Milled rice yield and HRY are expressed as mass percentages, whereas fissured kernels is expressed as a kernel-number percentage. Within MRY, HRY, and fissured-kernel sets, values followed by the same letter are not significantly different (*P* > 0.05). Bars are based on the mean values of three milling/fissure-count repetitions.

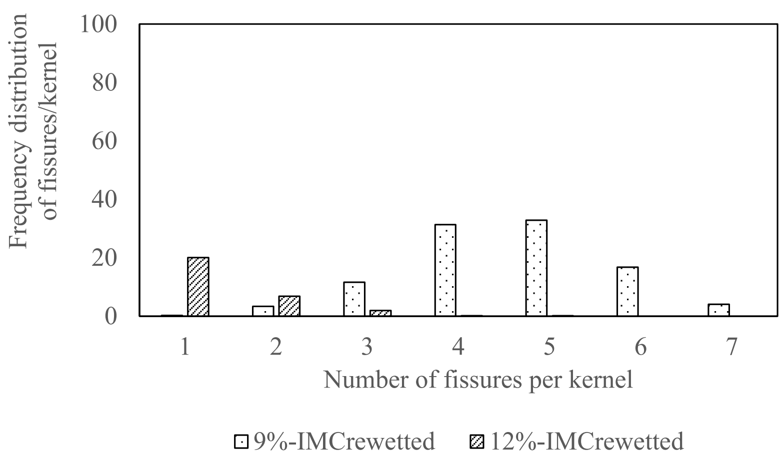


Fig. 3. Frequency distribution of fissures/kernel for cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then manually dehulled. Fissures were enumerated on 300 randomly selected brown rice kernels. Bars are based on the mean values of three fissure-count repetitions.

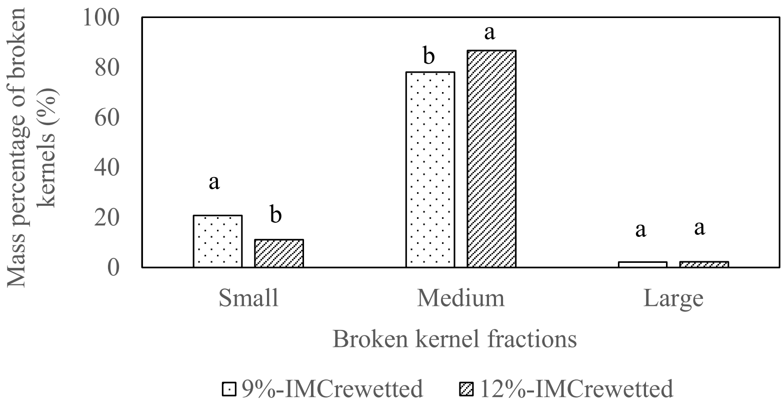


Fig. 4. Mass percentages of small, medium, and large brokens produced from cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. The sieves distributed the brokens into three fractions: "large" (retained on the 2-mm sieve), "medium" (passed through the 2-mm sieve but retained on the 1.68-mm sieve), and "small" (passed through the 1.68-mm sieve but retained on the 0.841-mm sieve). Within a brokens-fraction, values followed by the same letter are not significantly different (*P* > 0.05).

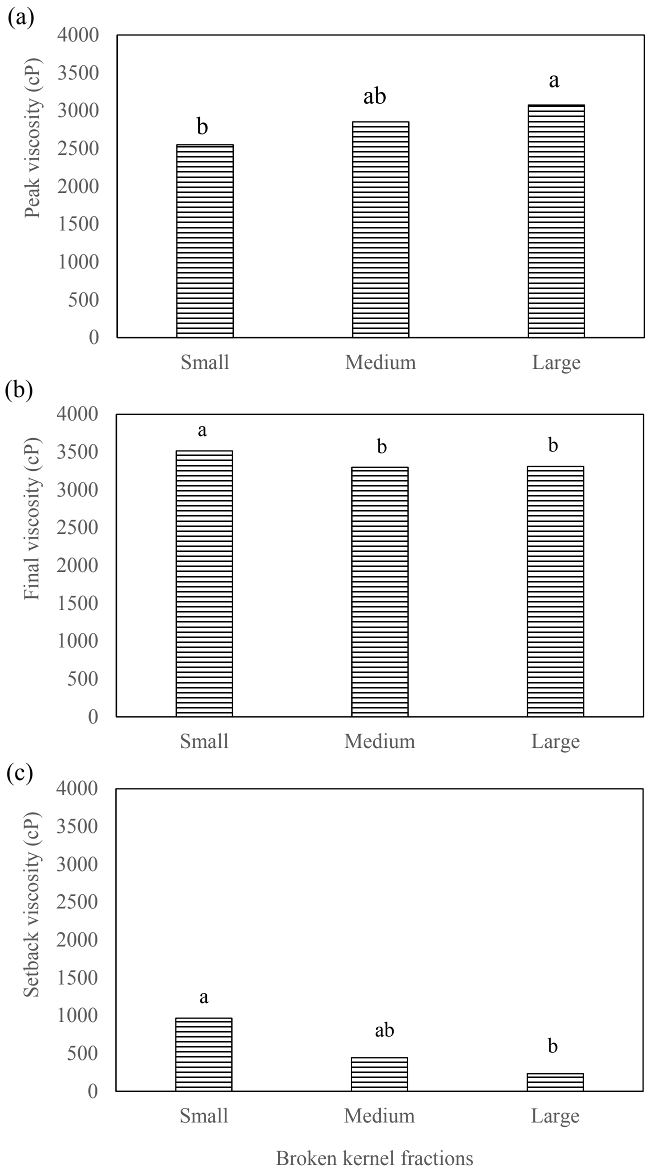


Fig. 5. Peak viscosity (a), final viscosity (b) and setback (c) of small, medium, and large brokens produced from cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. Since IMC did not affect pasting properties, results for the two rewetted sublots were pooled. For each viscosity parameter, values followed by the same letter are not significantly different (*P* > 0.05).

Effects of Chalkiness Level on Sensory Aspects of Raw and Cooked Rice

H.-S. Seo, C. Duez, S. Cho, Y.-J. Wang, and T.J. Siebenmorgen

ABSTRACT

The objective of this study was to determine whether the chalkiness level affects sensory attributes of raw and cooked rice. A total of 9 raw rice samples varying in chalkiness from 0% to 24% were presented to 87 North American rice consumers (47 Caucasians and 40 Asians). The participants evaluated the quality of the rice samples based on appearance and rated their overall impression of the samples. In addition, 10 trained panelists used 31 sensory attributes to evaluate cooked rice samples that were prepared from rice samples having 0%, 6%, 12%, 18%, and 24% chalkiness by area. With an increase of chalkiness of raw rice, consumers' overall impression of rice appearance, as well as their ratings of rice quality, decreased; this trend was more pronounced in Asians than in Caucasians. However, sensory attributes of cooked rice samples were not significantly different as a function of chalkiness level. The present findings demonstrate that the chalkiness level can affect consumer acceptability of raw rice samples, but once cooked, there was no difference in sensory response due to the level of chalk present in the raw rice.

INTRODUCTION

It is well known that appearance plays an important role in evaluating food (Francis, 1995), which, in turn, modulates not only consumers' willingness to buy (Alfnes et al., 2006), but also their acceptability of foods (Imram, 1999). Chalk, an opaque portion of rice kernels, is one of the critical factors determining appearance characteristics of rice. Chalky rice kernels have also been found to negatively impact cooking and eating quality of milled rice (Cheng et al., 2005). However, little published information is available on the influence of chalkiness level on consumers' perception and acceptability of raw rice. This study aimed to determine the chalkiness level that would have an effect on consumers' acceptability of raw rice. Additionally, since chalky portions of kernels are not visible after rice is cooked, sensory attributes including appearance, flavor, and texture were used by a descriptive sensory panel to evaluate the impact of raw rice chalkiness level on cooked rice acceptability.

PROCEDURES

Rice Sample and Preparation

Commercially milled, long-grain rice was separated into 2 lots, 6% and 24% chalk, by area, using a commercial color sorter. In addition, another lot (referred to as "0%" chalk) was prepared from the 6% lot by manually removing chalky kernels. As shown in Fig. 1, a total of 9 rice samples, varying in chalkiness level, were prepared by mixing these 3 lots (0%, 6%, and 24% chalk, by area) of rice samples in various preparations: 0%, 3%, 6%, 9%, 12%, 15%, 18%, 21%, and 24%. The chalkiness level of each rice sample was determined in triplicate using an image analysis system (WinSEEDLE Pro 2005aTM, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Whiteness level (L* value) of raw and cooked rice samples was measured in triplicate using a colorimeter (Minolta CR-300, Minolta Corp., Ramsey, N.J.).

Sensory Evaluation of Raw Rice Samples Varying in Chalkiness Level

Eighty-seven North American rice consumers ranging in age from 19 to 66 years (mean age: 36 years) participated in this study. All participants reported that they had bought or consumed rice at least once last month. To examine whether consumer ethnicity affects sensory perception of raw rice samples, 47 Caucasians (20 males and 27 females) and 40 Asians (21 males and 19 females) were recruited.

Each (200 g) of 9 rice samples was wrapped in a transparent plastic film packet (15 cm × 7.5 cm) and then sealed and identified by a 3-digit code. All samples were randomly presented, one after another, to each participant. For each sample, participants were asked to rate rice quality, based on appearance, using a 9-point Likert scale ranging from 1 (extremely bad) to 9 (extremely good). The participants were then asked to rate their overall impression of rice appearance on a 9-point Likert scale ranging from 1 (dislike extremely) to 9 (like extremely). Participants were allowed to touch and flip the packet of rice while judging. There was no time limit for these ratings.

Descriptive Analysis of Cooked Rice Samples Prepared from Raw Rice Varying in Chalkiness Level

Descriptive sensory analysis was conducted at the University of Arkansas System Division of Agriculture's Sensory Service Center (Fayetteville, Ark.). Ten descriptive panelists, each with an average experience of 1,000 h in evaluating various food products, participated in this study. Following a 3-h orientation/panel discussion session and conforming to the Spectrum method (Sensory Spectrum Inc., Chatham, N.J.), 31 sensory attributes of cooked rice were developed.

Among the 9 samples, 6 rice samples varying in chalkiness level: 0%, 6%, 9%, 12%, 18%, and 24% were used for the descriptive sensory analysis of cooked rice. Three-hundred grams of each rice sample were cooked in an electronic rice cooker (RC 101 Rice Cooker, Rival, Milford, Mass.) with a 1:2 rice-to-water ratio. After being cooled to room temperature for 10 min, each of the cooked rice samples was presented in a glass bowl covered with a watch glass. The five samples were presented one after another with a time interval of 10 min. Intensities of each of the 31 sensory attributes were evaluated on a 15-point numerical scale with 0.1 increments ballots, where 0 represents "none" and 15 represents "extremely strong." Each sample was evaluated twice in two consecutive testing sessions.

Data analysis was performed using JMP Pro v. 11.0 (SAS Institute Inc., Cary, N.C.). A statistically significant difference was defined as $P < 0.05$.

RESULTS AND DISCUSSION

Effect of Chalkiness Level on Sensory Aspects of Raw Rice

Table 1 shows chalkiness level and whiteness level (L* value) of the 9 rice samples used in this study. A statistical analysis revealed that there were statistical differences in the quality rating for a rice sample as given by Asian versus Caucasian consumers, and that the magnitudes of the difference depended on the chalkiness level. As shown in Fig. 2a, Asian consumers were more influenced by the chalkiness level compared to Caucasian consumers. In other words, with an increase in chalkiness, Asian consumers' rice quality ratings decreased more dramatically than did Caucasian consumers' ratings. However, there was no effect of ethnicity (i.e., Caucasians versus Asians) on rice quality ratings when the consumers evaluated rice samples with 3% or less chalk by area ($P > 0.05$).

Similarly, there was a significant interaction between chalkiness level and ethnicity in the ratings of overall impression of rice appearance ($P < 0.001$). Figure 2b shows that the overall impression of rice appearance decreased with an increase of chalkiness level, and this trend was more evident in Asian consumers than in Caucasian consumers. There was no significant effect of ethnicity on the overall impression of rice appearance in rice samples with 3% or less chalk by area ($P > 0.05$).

Effect of Chalkiness Level on Sensory Aspects of Cooked Rice

Perceived intensities of sensory attributes of cooked rice were not significantly different among the five rice samples ($P > 0.05$). Therefore, although the rice quality and overall impression of appearance of uncooked rice were affected by chalkiness level, no significant effect of chalkiness level on sensory attributes of cooked rice was found by the trained panel.

SIGNIFICANCE OF FINDINGS

Increases in chalkiness level have been associated with high nighttime air temperatures during kernel development. As a result, there is a growing interest in the effect of chalkiness level on sensory attributes of rice. The present findings demonstrate that overall impression of appearance of uncooked rice is affected by chalkiness level and ethnicity (Caucasians vs. Asians), but once rice is cooked, chalkiness level of the uncooked rice makes no difference.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board for financial support.

LITERATURE CITED

Alfnes, F., A.G. Guttormsen, G. Steine, and K. Kolstad. 2006. Consumers' willingness to pay for the color of salmon: A choice experiment with real economic incentives. Am. J. Agric. Econ. 88:1050-1061.

Cheng, F.M., L.J. Zhong, F. Wang, and G.P. Zhang. 2005. Differences in cooking and eating properties between chalky and translucent parts in rice grains. Food Chem. 90:39-46.

Francis, F.J. 1995. Quality as influenced by color. Food Qual. Pref. 6:149-155.

Imram, N. 1999. The role of visual cues in consumer perception and acceptance of a food product. Nutr. Food Sci. 99:224-230.

Table 1. Chalkiness level and whiteness level of the commercially milled rice samples used in this study.

	Sample (chalkiness level)								
	0%	3%	6%	9%	12%	15%	18%	21%	24%
Chalkiness level (%)[a]	0.4 (± 0.1)	2.6 (± 1.3)	6.6 (± 0.5)	9.5 (± 0.8)	11.8 (± 3.7)	16.1 (± 1.7)	18.7 (± 2.2)	20.0 (± 5.4)	24.3 (± 1.9)
Whiteness level (L* value)	73.4 (± 0.4)	74.1 (± 0.6)	74.7 (± 0.4)	74.7 (± 0.5)	74.9 (± 0.3)	75.6 (± 0.3)	76.2 (± 0.7)	76.2 (± 0.5)	77.0 (± 0.4)

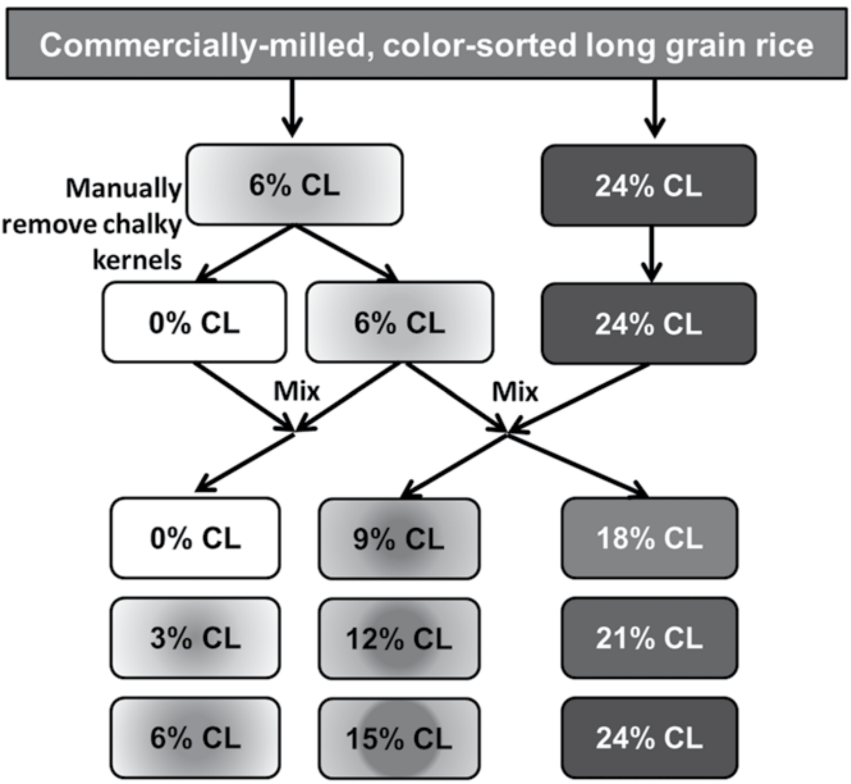


Fig. 1. The scheme used for sample preparation in this study. Abbreviation: CL = chalkiness level.

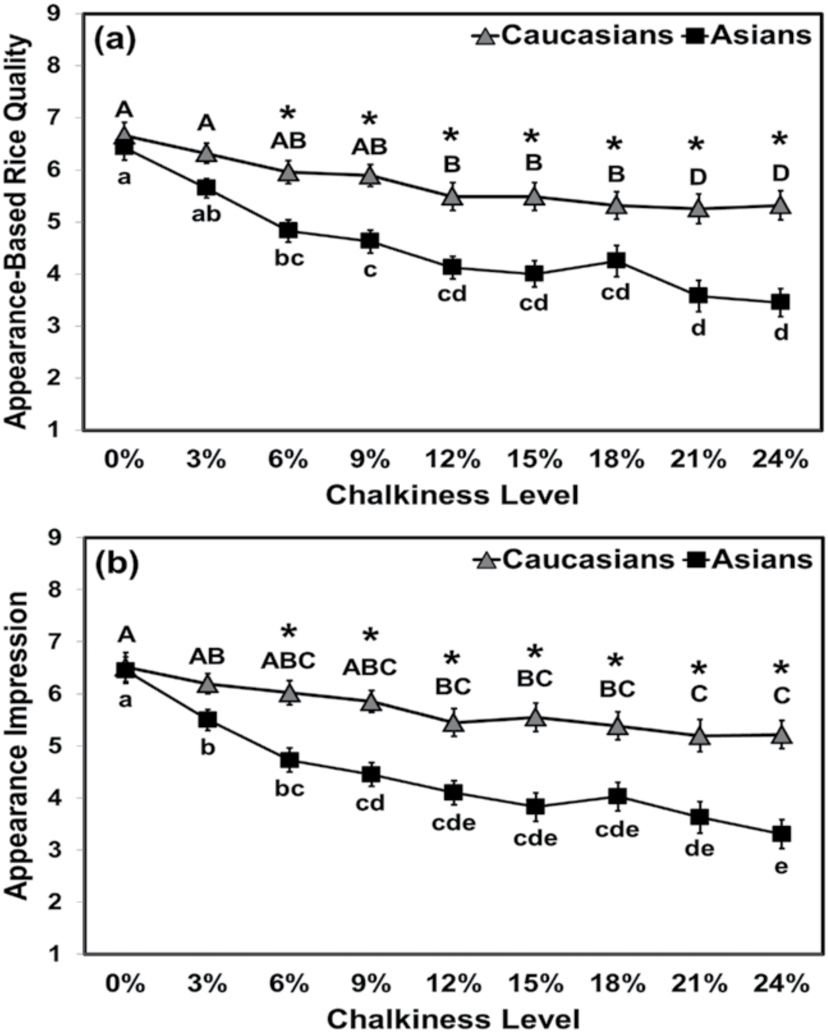


Fig. 2. Mean ratings of rice quality (a) and overall impression of appearance (b) of uncooked rice as a function of chalkiness level and ethnicity (Caucasians vs. Asians). Different capital (or small) letters indicate a significant difference between the rice samples at *P* < 0.05 in Caucasian (or Asian) consumers' ratings, respectively. An asterisk indicates a significant difference of the ratings between the two ethnicities at *P* < 0.05. Error bars represent a standard error of the mean.

Genetically Modified Rice Commercialization and Its Impact on the Global Rice Economy

A. Durand-Morat, E.C. Chavez, and E.J. Wailes

ABSTRACT

Genetically modified (GM) rice is an important technology surrounded with controversy and uncertainty, hence it warrants more in-depth analysis. While GM rice is considered by its supporters as having promising potential, many still remain passionately against its use. This study assesses the impacts of GM rice commercialization on the global rice market. We used the Arkansas Global Rice Model (AGRM) and the RICEFLOW model to provide stochastic and dynamic analyses. Scenarios of adoption, diffusion, and acceptance of *Bt* (*Bacillus thuringiensis*) rice by Bangladesh, China, Indonesia, Nigeria, and the Philippines are compared against baseline projections. The results focus on world trade, world and domestic prices, resource savings, domestic production, consumption, and stocks. The adoption of *Bt* rice has the potential to significantly impact the global and national rice economies. Total rice trade, international price, and domestic prices decline as global rice production, consumption, and stocks expand.

INTRODUCTION

Projections indicate a steady growth of about 1% per year in global demand for rice over the next decade, driven primarily by population growth in important rice-consuming areas in Africa and the Middle East. The supply side is expected to cope with the demand; and under the assumption of average normal weather, steady reasonable increases in prices are projected, as importing countries become more attuned to improving food security through trade (Wailes and Chavez, 2015). Yet growth in rice yield lags behind that of population over the last several years, putting more pressure on already scarce resources to cope with demand and ameliorate the effect on food security, primarily of the poorest segments of the population (IRRI, 2010). Given limited arable area for expansion, sustainability of production over the long run must come from productivity gains. The introduction of high-yielding rice varieties during the Green Revolution led to significant productivity increases and steady decreases in rice prices from 1975 to 2000. A new boost in rice productivity is urgently needed to cope with increasing demand and limiting production resources (Dawe et al., 2010), and the "gene revolution" may be one of the many tools that can help achieve the intended goal.

Adoption of new seed technologies with higher productivity potentials, including genetically modified (GM) rice, is one of several approaches to improve rice land and water productivity. Yet rice and wheat, the two main food crops, are being held hostage by the controversy over GM technology (Demont and Stein, 2013). Stem borer is the most significant rice insect pest in most Asian countries, particularly in irrigated systems, and therefore the *Bt* technology holds great potential to boost productivity in those environments. *Bacillus thuringiensis* rice contains genetic material from a strain of the naturally occurring soil bacteria *Bacillus thuringiensis* that codes the production of the Cry proteins that kill insects with alkaline digestive systems (Romeis et al., 2006). Genetically modified rice varieties with agronomic and nutritional benefits have been in the pipeline for well over a decade (Demont et al., 2013). Herbicide-tolerant GM rice includes Liberty-Link rice (resistant to glufosinate), Roundup-Ready rice (resistant to glyphosate); insect-resistance rice includes *Bt* rice (resistant to lepidopterous pests of rice, including stem borers and leaffolders); second generation, nutritionally enhanced GM rice includes golden rice (with higher content of beta-carotene, a precursor of Vitamin A), and high-iron content rice.

Despite the potential of these developments, no approval for commercialization has been granted thus far anywhere in the world except for *Bt* rice in Iran in 2004, after which the permit was canceled (Ruane, 2013). China granted biosafety clearance for *Bt* rice in 2009, a step thought by many to clear the way for GM rice in the coming years, but unexpectedly refused to renew the certificates in 2014 (Normile, 2014). Attacks on golden rice field trials in the Philippines in 2013 also undermined efforts to commercialize the nutritionally enhanced rice, a technology that could improve the living standards of millions of people. Controversy over GM food in other Asian countries (e.g., *Bt* eggplant in India and Bangladesh) suggest that commercialization of GM rice still has a long way to go.

Assessments of benefits of GM rice vary by country, trait, assumed adoption rates, and modeling framework (for a review of this literature see Demont and Stein, 2013), and are relevant not only to ascertain the potential spread of a technology but also could help in the approval process. This study aims to complement previous analyses by using more detailed modeling frameworks of the global rice economy and updated databases, allowing for a meticulous disaggregation of impacts across rice types and market players.

PROCEDURES

The Arkansas Global Rice Model (AGRM; Wailes and Chavez, 2011) and RICEFLOW model (Durand-Morat and Wailes, 2010) are used as frameworks for this analysis. The AGRM is a non-spatial, multi-country/regional statistical simulation and econometric framework that disaggregates the rice market into 51 countries/regions. Each country or regional model includes a supply sector (harvested area and yields), a demand sector (per capita use), with trade, stocks and price linkage equations. Individual country models are linked through net trade, a specification that highlights the interdependence of countries in the world rice economy. Simulation is conducted for the purpose of generating 10-year projections that reflect the current state and the expected directions of the rice economies in the world by assessing their potential supply and demand paths over the next decade. This set of projections serves as a baseline for evaluating and comparing alternative macroeconomic, policy, weather, and technological scenarios. Equilibrium international prices are generated by balancing exports and imports.

The RICEFLOW model is a multi-region, multi-product, spatial partial equilibrium model of the global rice market. Production is specified as a two-level, separable, constant-return-to-scale (CES) technology. Substitution between imports and domestic production is specified as a CES using Armington elasticity of substitution. Factors of production are classified into perfectly mobile and sluggish. Mobile factors earn the same return across all production sectors; sluggish factors, on the other hand, earn different returns across sectors. The model accounts for policy intervention on factors of production, intermediate inputs, total output, trade, and final consumption. Final consumption is represented by an isoelastic demand function accounting for own and cross price as well as income effects. Finally, accounting equations guarantee that all markets (output, factors of production, intermediate inputs) clear at equilibrium, and that firms earn normal profits. The model is flexible with regard to the specification of production technologies (including trade), which can be specified as a CES, Cobb-Douglas, or Leontief technology. The database used to calibrate the RICEFLOW model represents the global rice market situation in the calendar year 2013. It includes data on production (cost, volume, and value), changes in inventories, bilateral trade, final and intermediate consumption, and policies (input, output, consumption, and trade), by rice type (long-grain, medium-grain, and fragrant) and milling degree (paddy, brown, and milled). The database is disaggregated into 68 countries and 5 aggregate regions.

Two scenarios are analyzed using the AGRM model: ***Scenario A1***–*Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines; and ***Scenario A2***–*Bt* adoption rate of 20% for Nigeria and 40% for the other four countries to assess the effect of asymmetric adoption of technology. The adoption function of *Bt* rice is assumed to follow the same pattern as GM crops in the U.S. (USDA-ERS, 2014) for a 9-year projection period up to 2023. The *Bt* yield gain is assumed to be 5%.

RICEFLOW is updated to year 2023 using forecasts for key exogenous variables (e.g., population, GDP, and energy prices) from which a baseline is generated. One scenario was analyzed using RICEFLOW: ***Scenario R1***–The *Bt* adoption rate of 40% of the acreage in Bangladesh, China, Indonesia, Nigeria, and the Philippines. The *Bt* rice generates a 5% yield gain over currently used varieties, a 5% gain in the productivity of factors of production (land, labor, and capital), and a 50% reduction in pesticide use.

RESULTS AND DISCUSSION[1]

Arkansas Global Rice Model Results

The annual impacts of *Bt* rice adoption increase over the projection period, as the adoption schedule used in the analysis follows an increasing path until the full adoption is reached by the end of the period. Over the 9-year period analyzed, the annual aggregate impacts of the *Bt* rice adoption on the global rice market for scenarios A1 and A2 are presented in Table 1. The international rice price declines by nearly 6% annually, on average under both scenarios as a result of a lower demand for imports in *Bt*-rice-adopting countries. Production expands in all adopting countries to varying degrees, leading to a marginal gain in global production. Consumption increases in adopting and non-adopting countries alike as a result of lower equilibrium prices, leading to a marginal increase in global consumption. There is significant import substitution in adopting countries, which is only partially offset by higher imports by non-adopters as a result of lower international prices. Domestic rice prices in all five rice-importing countries decline by 1.7% to 6.2%/year.

Aggregate rice exports from Thailand, Pakistan, Myanmar, Vietnam, Cambodia, and India decrease by 2.1% [729 thousand metric tons (tmt)/year] and 2.0% (722 tmt/year) under scenarios A1and A2, respectively (Table 2). The scenario impacts on exports differ across countries. For U.S. rice exports, the impact is minor. For Myanmar, impacts on exports are relatively more substantial because of the bigger increases in rice use per capita as a result of the lower prices, compared to the other major countries like Thailand, India, and Pakistan. One reason is that these countries account for much bigger shares of baseline global export trade. Table 3 shows that import substitution occurs in all the importing countries analyzed, with China experiencing the biggest average annual import decline of 48.7% [equivalent to nearly 1.49 million metric tons (mmt)/year]; followed by Bangladesh (13.4% or 237 tmt/year); and Indonesia (20% or 160 tmt/year). Rice imports by the Philippines decline modestly, i.e., by 3.7% or 31 tmt/year; while Nigeria's annual imports are down marginally, i.e., by 5 tmt/year. In general, rice consumption expands from 0.3% to 0.6%, as domestic prices decline.

While the lower *Bt* adoption rate (20%) for Nigeria under scenario A2 has minimal impacts on the global rice market, it has significant implications for Nigeria, which experiences expansion of imports due to the smaller output gains under scenario A2 than under scenario A1 (Table 4). The annual changes in international prices, production, consumption and trade are less than 1%/year. The same magnitude of changes occurs on domestic prices of all the countries analyzed. Changes in Nigeria's domestic rice market under the 20% adoption rate are substantially different from that of the 40% rate. Instead of declining, Nigeria's rice imports under the lower adoption rate increase by 24 tmt/year due to the lower gain in production (-29 tmt/year), while the average increases in total consumption for both scenarios are comparable.

These results indicate that asymmetry in adoption of new technology such as *Bt* rice has important implications on relative domestic supply and demand hence an

[1] Although more projections for supply and demand variables are generated for the countries covered by AGRM and RICEFLOW, only selected variables are included in this report due to space consideration.

important food security issue especially for food-deficit countries like Nigeria. The rate of production growth under scenario A1 is more than double that of the rate under scenario A2, making Nigeria more dependent on imports under scenario A2.

RICEFLOW Results

The GM rice adoption as specified in scenario R1 is expected to marginally expand global rice supply (0.2%) and demand (0.2%), and reduce global trade by 2.0% (Table 5). The stochastic analysis suggests *Bt* rice adoption may also skew global production and trade slightly to the left (Figs. 1 and 3). As a result of *Bt* rice adoption, the global value of production is estimated to decrease by U.S. $3.9 billion[2] while savings from global rice consumption are estimated at U.S. $ 5.1 billion. The technological improvement is expected to release the pressure on land demand, which is estimated to contract globally by 0.5%.

The long-grain segment of the rice market is expected to experience the largest shocks due to the adoption of *Bt* rice. The segmentation of the impact follows from the assumption that biotechnology companies will first introduce *Bt* long-grain rice varieties to take advantage of the size of the market[3]. Global supply and demand of long-grain rice are expected to increase by 0.3%. The proposed technological change is estimated to slightly increase the skewness of long-grain production to the left, while marginally decreasing the skewness of production of medium-grain and fragrant rice (Fig. 2). Total trade of long-grain rice is estimated to decrease by 2.7% (Table 5), and its distribution to become slightly more skewed to the left (Fig. 3).

Spillovers to other segments of the rice market (medium-/short-grain, and fragrant rice) through factor markets and final consumption are for the most part marginal, except for fragrant rice production in Vietnam and Pakistan, which increases by 1.0% and 0.4%, respectively, as a result of the increased price competitiveness vis-à-vis long-grain rice—which in turn expands their exports. Production is estimated to increase among all GM-rice-adopting countries and leads to lower producer prices and improved competitiveness (Table 5 and Fig. 1). The drop in producer prices more than offsets the increase in production in all adopting countries but Nigeria, resulting in decreases in the total value of production. Nigeria is the most import-dependent among the adopters; with roughly 50% of 2013 consumption met through trade, primarily from India and Thailand. The adoption of *Bt* rice gives the domestic supply chain a competitive edge over imports that encourages a relatively strong expansion of domestic production, assuming that the country's plentiful land and water resources can be developed.

[2] This does not mean a loss to producers worldwide since the assumption of zero (normal) profits is maintained throughout the simulation. This figure should be understood as the cost savings generated by the technology due to the improved efficiency in the use of production resources.

[3] Recall that scenario *R1* assumes that GM rice is first introduced only on long grain rice to take advantage of the scale. Long grain accounts for roughly 85% of global rice production in 2013.

Among non-adopters, the Vietnamese supply chain is expected to be the most affected due to its strong trade linkages with adopting nations[4]. The volume and value of rice production is expected to decrease by 1.7% and U.S. $200 million, while total exports shrink by 6.8%. Consumers from all regions will benefit from lower prices. In relative terms, the largest drop in consumer prices is expected in the Philippines (-4.1%) and China (-3.5%). In absolute terms, the largest savings from rice consumption are projected to occur in China (U.S. $3.3 billion) and Indonesia (U.S. $824 million). Meanwhile, Vietnamese consumers are expected to reap the largest benefits/savings among non-adopters. Figure 4 shows the cumulative distribution function (cdf) for consumer prices in the five *Bt*-rice-adopting countries. Estimations suggest that consumer prices in Bangladesh, China, and Indonesia will decrease with certainty in both the benchmark and scenario R1. Adoption of *Bt* rice increases the probability of consumer prices dropping only slightly in Nigeria and more significantly in the Philippines.

Demand for land eases and returns decrease in all countries except Nigeria and the Philippines. Land demand in China and India, which together account for 46% of total rice acreage in 2013, decreases by 0.3% or 190 thousand hectares as a result of *Bt* rice adoption. Although a marginal effect, the results show the importance of adopting land and water saving technologies to better cope with tighter resource supplies in the coming years. Most Asian countries face mounting pressures to improve land and water productivity to sustain rice production and food security.

SIGNIFICANCE OF FINDINGS

The results suggest that the adoption of *Bt* rice in selected importing countries will generate significant import substitution effects that will ameliorate the substantial expansion in international trade projected over the next decade. Using the two models, results suggest that import substitution in China could range from moderate to over 85% by 2023. In general, consumers worldwide are expected to benefit from lower prices, with the largest benefits accruing to consumers of long-grain rice. Adoption of *Bt* rice also eases the pressure on land demand and leads to lower land rental prices in most countries. At the global level, impacts of *Bt* rice adoption are mostly marginal except for the international reference price, which is estimated to decrease by 6% a year as a result of the adoption rates and yield gains assumed in this study. Lagging in *Bt* rice adoption could have significant welfare costs, providing incentive for countries to keep up with the leading new technology adopters.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas rice farmers who provided support through the rice check-off funds administered by the Rice Research and Promotion Board, which

[4] Around 45% of Vietnam's rice exports went to *Bt* rice adopters (Bangladesh, China, Indonesia, Nigeria, and the Philippines) in 2013.

provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model and the RICEFLOW. The Arkansas Global Rice Model (AGRM) was updated twice in 2014 and once in January 2015 in collaboration with FAPRI-Missouri which provided the bulk of the funds for the global rice modeling program. RICEFLOW was updated in early 2014, by calibrating data to 2013.

LITERATURE CITED

Dawe, D., S. Pandey, and A. Nelson. 2010. Emerging trends and spatial patterns of rice production. *In:* S. Pandey, D. Byerlee, D. Dawe, A. Dobermann, S. Mohanty, S. Rozelle, and B. Hardy (eds.). Rice in the global economy: strategic research and policy issues for food security. Los Baños (Philippines): International Rice Research Institute. 477 pp.

Demont, M. and A.J. Stein. 2013. Global value of GM rice: a review of expected agronomic and consumer benefits. New Biotechnology 30(5):427-436.

Demont, M., M. Chen, G. Ye, and A.J. Stein. 2013. Rice. Chapter 42 *In:* S.J. Smyth, D. Castle, and P.W.B. Phillips (eds.). Handbook on agriculture, biotechnology and development. Northampton, Mass. Edward Elgar Publishing.

Durand-Morat, A. and E.J. Wailes. 2010. RICEFLOW: A Multi-Region, Multi-Product, Spatial Partial Equilibrium Model of the World Rice Economy. Department of Agricultural Economics and Agribusiness Staff Paper 03 2010. Fayetteville, Ark.: University of Arkansas.

IRRI. 2010. International Rice Research Institute. Rice in the global economy: strategic research and policy issues for food security. S. Pandey, D. Byerlee, D. Dawe, A. Dobermann, S. Mohanty, S. Rozelle, and B. Hardy (eds.). Los Baños, Philippines. 477 pp.

Normile, D. 2014. China pulls plugs on genetically modified rice and corn. American Association for the Advancement of Science, Science Insider. Available at: http://news.sciencemag.org/asiapacific/2014/08/china-pulls-plug-genetically-modified-rice-and-corn

Romeis, J., M. Meissle, and F. Bigler. 2006. Transgenic Crops Expressing *Bacillus thuringiensis* Toxins and Biological Control. Nature Biotechnology 24(1):63-71.

Ruane, J. 2013. An FAO e-mail conference on GMOs in the pipeline in developing countries: The moderator's summary. FAO. Available at: http://www.fao.org/biotech/biotech-forum/

USDA-ERS. United States Department of Agriculture-Economic Research Service. 2014. Recent Trends in GE Adoption. Accessed 2 February 2015. Available at: http://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx

Wailes, E.J. and E. Chavez. 2011. 2011 Updated Arkansas Global Rice Model. Department of Agricultural Economics and Agribusiness Staff Paper 01 2011. Fayetteville, Ark. University of Arkansas. Available at: http://ageconsearch.umn.edu/bitstream/102650/2/AGRM%20MODEL%20DOCUMENTATION_revised%20April%2013%202011.pdf

Wailes, E. and E. Chavez. 2015. International Rice Baseline Projections 2014-2024. Arkansas Global Rice Economics Program, Department of Agricultural Economics and Agribusiness. Fayetteville, Ark., University of Arkansas. Staff Paper 01 2015. Available at: http://ageconsearch.umn.edu/handle/199846

Table 1. Impacts of scenarios A1 (*Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines); and A2 (*Bt* adoption rate of 20% for Nigeria and 40% for the other four countries) on international rice price and world supply and use.

Variable	Version	Unit[a]	2015	2023	9-year average
International Reference Price	Baseline	U.S. $/mt	404	422	412
	Scenario A1	% Change	-1.36	-8.68	-5.67
	Scenario A2	% Change	-1.35	-8.60	-5.62
Area Harvested	Baseline	(mil. ha)	160	161	161
	Scenario A1	% Change	0.00	-0.32	-0.16
	Scenario A2	% Change	0.00	-0.32	-0.16
Production	Baseline	(mil. mt)	483	520	502
	Scenario A1	% Change	0.11	0.55	0.41
	Scenario A2	% Change	0.11	0.55	0.41
Consumption	Baseline	(mil. mt)	487	519	504
	Scenario A1	% Change	0.11	0.62	0.41
	Scenario A2	% Change	0.10	0.61	0.40
Total Trade	Baseline	(mil. mt)	42	49	46
	Scenario A1	% Change	-0.51	-2.69	-1.78
	Scenario A2	% Change	-0.51	-2.66	-1.77
Ending Stocks	Baseline	(mil. mt)	103	84	92
	Scenario A1	% Change	0.02	0.09	0.39
	Scenario A2	% Change	0.02	0.16	0.41

[a] mt = metric ton; mil. ha = million hectares; mil. mt = million metric tons.

Table 2. Impacts of scenarios A1 (*Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines) and A2 (*Bt* adoption rate of 20% for Nigeria and 40% for the other four countries) on rice net exports of selected countries.

Variable	Version	Unit[a]	2015	2023	9-year average
Thailand	Baseline	(tmt)	10188	11918	11349
	Scenario A1	% Change	-0.69	0.36	-0.47
	Scenario A2	% Change	-0.69	0.36	-0.47
Pakistan	Baseline	(tmt)	3479	4010	3676
	Scenario A1	% Change	-0.76	-7.11	-4.11
	Scenario A2	% Change	-0.76	-7.04	-4.07
Myanmar	Baseline	(tmt)	1054	1160	1074
	Scenario A1	% Change	-2.18	-16.46	-11.14
	Scenario A2	% Change	-2.16	-16.30	-11.03
Vietnam	Baseline	(tmt)	6488	8220	7418
	Scenario A1	% Change	-1.39	-3.86	-3.60
	Scenario A2	% Change	-1.38	-3.82	-3.57
Cambodia	Baseline	(tmt)	1241	1978	1594
	Scenario A1	% Change	-0.09	-10.78	-5.77
	Scenario A2	% Change	-0.09	-10.68	-5.71
India	Baseline	(tmt)	9065	10637	9604
	Scenario A1	% Change	0.05	-0.73	-0.29
	Scenario A2	% Change	0.05	-0.72	-0.29
USA	Baseline	(tmt)	2701	2337	2570
	Scenario A1	% Change	-0.14	-5.76	-1.18
	Scenario A2	% Change	-0.14	-5.71	-1.17

[a] tmt - thousand metric tons.

Table 3. Impacts of scenarios A1 (*Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines) and A2 (*Bt* adoption rate of 20% for Nigeria and 40% for the other four countries) on rice net imports of selected countries.

Variable	Version	Unit[a]	2015	2023	9-year average
China	Baseline	(tmt)	2844	3129	2995
	Scenario A1	% Change	-10.37	-85.66	-48.73
	Scenario A2	% Change	-10.37	-85.68	-48.74
Indonesia	Baseline	(tmt)	1088	1193	848
	Scenario A1	% Change	-2.29	-20.09	-20.00
	Scenario A2	% Change	-2.33	-20.65	-20.46
Philippines	Baseline	(tmt)	1126	550	848
	Scenario A1	% Change	-1.05	-2.88	-3.72
	Scenario A2	% Change	-1.08	-4.01	-4.18
Bangladesh	Baseline	(tmt)	1065	1952	1713
	Scenario A1	% Change	-7.44	-14.84	-13.38
	Scenario A2	% Change	-7.44	-15.17	-13.53
Nigeria	Baseline	(tmt)	3402	3792	3619
	Scenario A1	% Change	-0.05	-0.25	-0.12
	Scenario A2	% Change	0.05	1.10	0.64

[a] tmt = thousand metric tons.

Table 4. Impacts of scenarios A1 (*Bt* adoption rate of 40% of the rice area in Bangladesh, China, Indonesia, Nigeria, and the Philippines) and A2 (*Bt* adoption rate of 20% for Nigeria and 40% for the other four countries) on Nigeria's rice supply and use.

Variable	Version	Unit[a]	2015	2023	9-year average
Production	Baseline	(tmt)	3226	4697	3934
	Scenario A1	% Change	0.23	1.91	1.23
	Scenario A2	% Change	0.11	0.81	0.54
Consumption	Baseline	(tmt)	6611	8487	7545
	Scenario A1	% Change	0.08	0.95	0.59
	Scenario A2	% Change	0.08	0.94	0.59
Imports	Baseline	(tmt)	3402	3792	3619
	Scenario A1	% Change	-0.05	-0.25	-0.12
	Scenario A2	% Change	0.05	1.10	0.64

[a] tmt = thousand metric tons.

Table 5. Impact of scenario R1 (*Bt* adoption rate of 40% of the acreage in Bangladesh, China, Indonesia, Nigeria, and the Philippines; vis-à-vis the benchmark) on selected variables and countries.

Variables	WORLD[a]	BAN[b]	CHI	INDO	NIG	PHI	VIE	IND	PAK	THA	USA	MYA	MAL
Production	**1.7 (0.2%)**	**0.1%**	**0.9%**	**0.7%**	**4.7%**	**2.4%**	**-1.7%**	**-0.1%**	**-0.5%**	**-0.5%**	**-0.1%**	**-0.4%**	**-0.3%**
LG[c]	1.8 (0.3%)	0.1%	1.3%	0.7%	4.7%	2.4%	-1.8%	-0.1%	-1.0%	-0.6%	-0.1%	-0.4%	-0.3%
MG	-0.1 (-0.1%)	--	-0.1%	--	--	--	--	--	--	--	-0.1%	--	--
FR	0.0 (-0.1%)	--	--	--	--	--	1.0%	0.0%	0.4%	-0.1%	--	--	--
Producer prices	**--**	**-2.8%**	**-3.5%**	**-3.2%**	**-1.0%**	**-4.7%**	**-0.4%**	**-0.1%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.3%**	**-0.1%**
LG	--	-2.8%	-4.5%	-3.2%	-1.0%	-4.7%	-0.4%	-0.1%	-0.3%	-0.1%	-0.1%	-0.3%	-0.1%
MG	--	--	-0.2%	--	--	--	--	--	--	--	-0.1%	--	--
FR	--	--	--	--	--	--	-0.3%	-0.2%	-0.3%	-0.1%	--	--	--
Value production[d]	**-3,880.9**	**-340.1**	**-2,282.8**	**-654.1**	**43.3**	**-229.5**	**-200.4**	**-72.1**	**-14.3**	**-49.3**	**-6.3**	**-25.8**	**-3.9**
LG	-3,779.0	-340.1	-2,196.4	-654.1	43.3	-229.5	-203.1	-66.1	-15.4	-41.7	-4.4	-25.8	-3.9
MG	-91.2	--	-86.4	--	--	--	--	--	--	--	-1.9	--	--
FR	-10.8	--	--	--	--	--	2.8	-6.1	1.0	-7.6	--	--	--
Consumption	**1.1 (0.2%)**	**0.0%**	**0.5%**	**0.5%**	**0.1%**	**1.2%**	**0.1%**	**0.0%**	**0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**
LG	1.2 (0.3%)	0.0%	0.7%	0.5%	0.1%	1.2%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
MG	-0.1 (-0.1%)	--	-0.2%	-0.1%	--	--	--	--	0.0%	--	0.0%	--	0.0%
FR	0.0 (-0.1%)	--	-0.2%	-0.1%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	--	0.0%
Consumer prices	**--**	**-2.6%**	**-3.5%**	**-3.1%**	**-0.4%**	**-4.1%**	**-0.4%**	**-0.1%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.3%**	**-0.2%**
LG	--	-2.6%	-4.2%	-3.1%	-0.4%	-4.1%	-0.4%	-0.1%	-0.4%	-0.1%	-0.1%	-0.3%	-0.2%
MG	--	--	-0.2%	-0.1%	--	--	--	--	-0.1%	--	-0.1%	--	-0.1%
FR	--	--	-0.2%	-0.1%	-0.1%	-0.2%	-0.3%	-0.2%	-0.2%	-0.1%	-0.1%	--	-0.1%
Value consumption[d]	**-5,136.9**	**-426.6**	**-3,257.2**	**-823.4**	**-44.6**	**-396.6**	**-32.3**	**-27.6**	**-4.0**	**-11.4**	**-8.8**	**-11.7**	**-3.5**
LG	-4,983.6	-426.6	-3,141.0	-823.4	-44.6	-396.6	-32.1	-26.2	-2.2	-6.4	-4.2	-11.7	-3.4
MG	-124.0	--	-114.5	0.0	--	--	--	--	0.0	--	-2.9	--	0.0
FR	-29.3	--	-1.7	0.0	0.0	0.0	-0.2	-1.4	-1.8	-4.9	-1.8	--	-0.1
Imports	**-0.8 (-2.0%)**	**-8.2%**	**-14.6%**	**-10.5%**	**-2.2%**	**-17.3%**	**-12.5%**	**-0.1%**	**3.4%**	**-1.2%**	**0.1%**	**-1.8%**	**0.7%**
LG	-0.8 (-2.7%)	-8.2%	-16.2%	-10.6%	-2.2%	-17.5%	-12.5%	-0.1%	5.2%	-1.2%	0.4%	-1.8%	0.8%
MG	0.0 (0.0%)	--	--	-0.1%	--	--	--	--	0.0%	--	--	--	--
FR	0.0 (0.1%)	--	0.1%	0.0%	--	-0.2%	--	--	-0.5%	0.0%	0.0%	--	0.1%

continued

Table 5. Continued.

Variables	WORLD[a]	BAN[b]	CHI	INDO	NIG	PHI	VIE	IND	PAK	THA	USA	MYA	MAL
Exports	**-0.8 (-2.0%)**	**--**	**2.8%**	**--**	**--**	**--**	**-6.8%**	**-1.1%**	**-0.2%**	**-1.5%**	**-0.2%**	**-3.8%**	**--**
LG	-0.8 (-2.7%)	--	43.7%	--	--	--	-7.8%	-1.7%	-0.6%	-1.8%	-0.2%	-3.8%	--
MG	0.0 (0.0%)	--	0.7%	--	--	--	--	--	--	--	-0.2%	--	--
FR	0.0 (0.1%)	--	--	--	--	--	1.1%	-0.1%	0.7%	-0.5%	--	--	--
Rice acreage	**-0.75 (-0.5%)**	**-1.7%**	**-0.5%**	**-1.3%**	**1.5%**	**0.0%**	**-1.5%**	**-0.1%**	**-0.4%**	**-0.4%**	**-0.1%**	**-0.4%**	**-0.3%**
Land rental price	**--**	**-5.4%**	**-1.7%**	**-4.6%**	**13.2%**	**0.0%**	**-5.5%**	**-0.4%**	**-2.2%**	**-1.6%**	**-0.5%**	**-2.1%**	**-1.4%**

[a] Nominal values in million metric tons or hectares.

[b] BAN = Bangladesh; CHI = China; INDO = Indonesia; NIG = Nigeria; PHI = Philippines; VIE = Vietnam; IND = India; PAK = Pakistan; THA = Thailand; USA = United States of America; MYA = Myanmar; and MAL = Malaysia.

[c] LG = long-grain; MG = medium grain, and FR = fragrant rice.

[d] Million 2013 U.S. dollars.

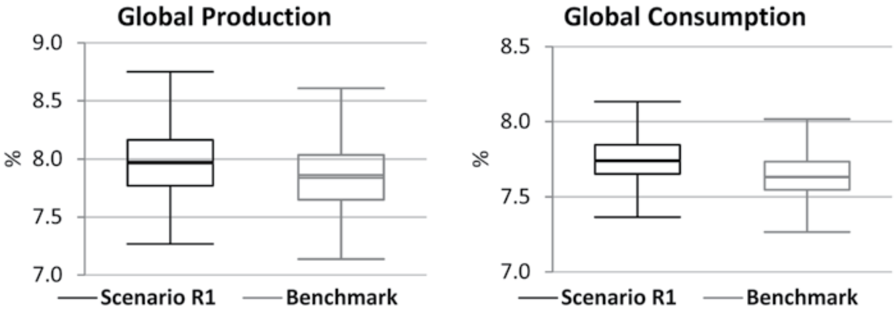


Fig. 1. Box plots for accumulated 2013-23 global rice production and consumption in the benchmark and scenario R1 (Bt adoption rate of 40% of the acreage in Bangladesh, China, Indonesia, Nigeria, and the Philippines).

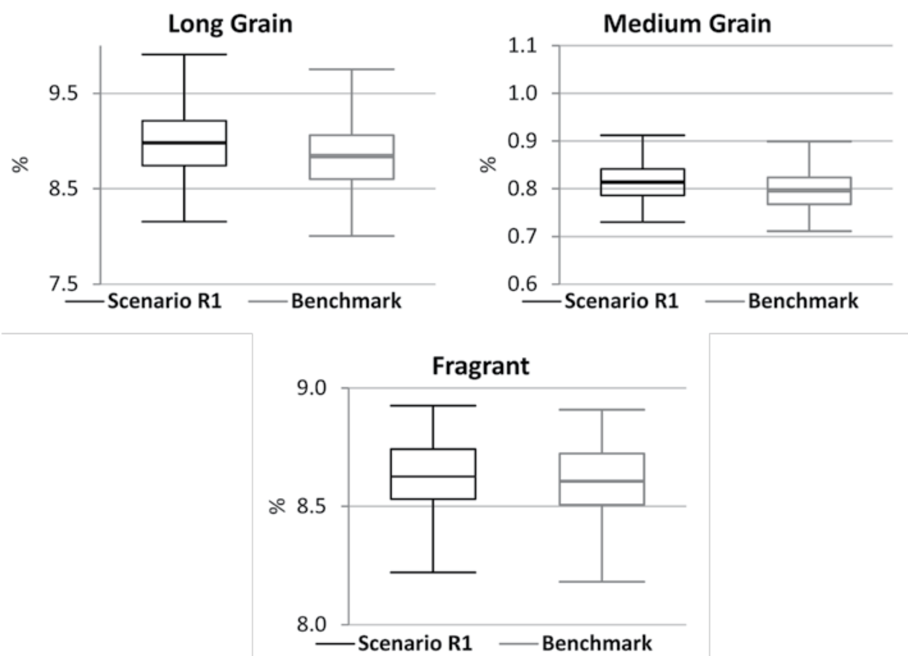


Fig. 2. Box plot for accumulated 2013-23 rice production by type in the benchmark and scenario R1 (Bt adoption rate of 40% of the acreage in Bangladesh, China, Indonesia, Nigeria, and the Philippines).

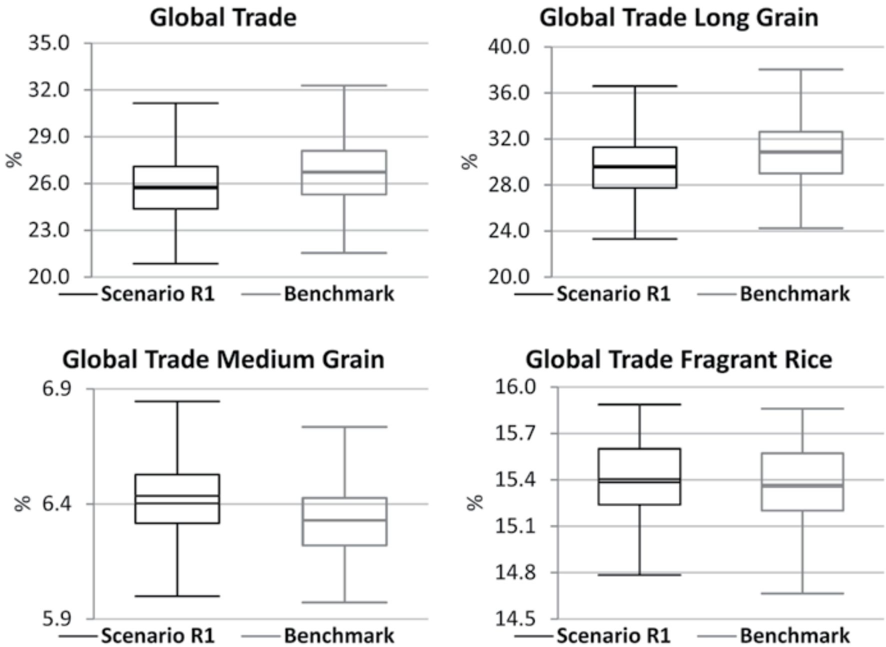


Fig. 3. Box plots for accumulated 2013-23 global rice trade by type in the benchmark and scenario R1 (Bt adoption rate of 40% of the acreage in Bangladesh, China, Indonesia, Nigeria, and the Philippines).

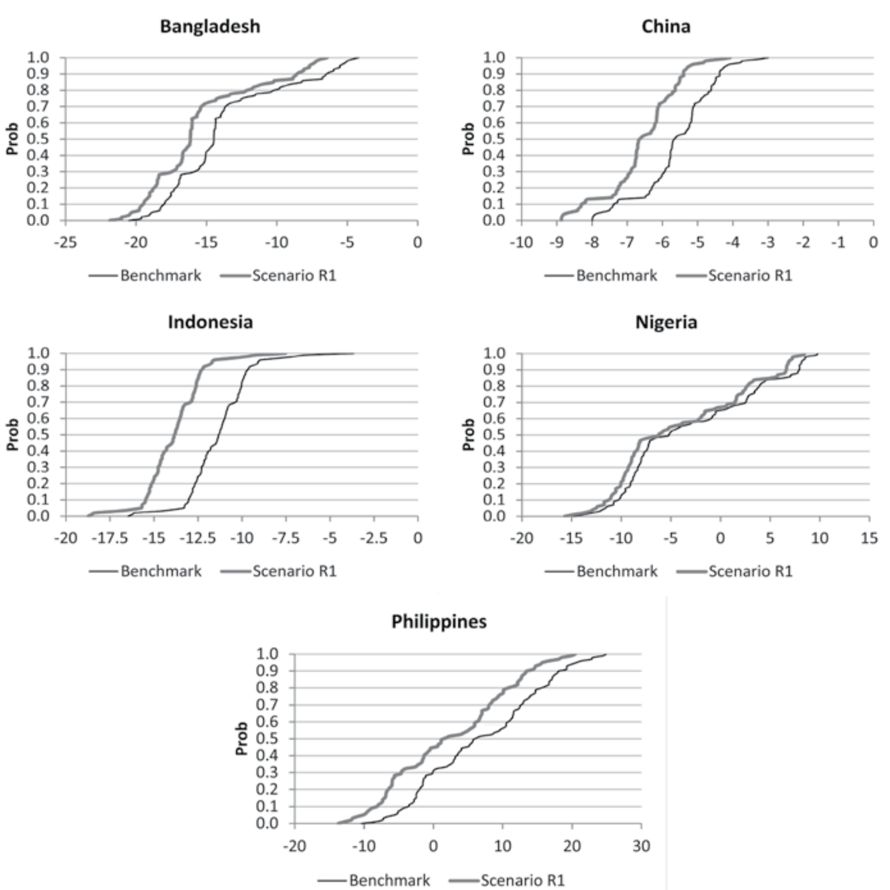


Fig. 4. Cumulative distribution function (cdf) of accumulated 2013-23 change in consumer prices among *Bt* rice adopters by country.

ECONOMICS

Rice Enterprise Budgets and Production Economic Analysis

W.A. Flanders

ABSTRACT

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations from the Rice Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information from producers for their production practices. The budget program is utilized to conduct economic analysis of field data in the Rice Research Verification Program.

INTRODUCTION

Technologies are continually changing for rice production. Simultaneously, volatile commodity prices and input prices present challenges for producers to maintain profitability. Producers need a means to calculate costs and returns of production alternatives to estimate potential profitability. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns.

PROCEDURES

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining costs information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2014). Labor costs in crop enterprise budgets represent time devoted to specified field activities.

Ownership costs of machinery are determined by the capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported in November 2014. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Iron Solutions, 2014). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and projected commodity prices.

RESULTS AND DISCUSSION

The University of Arkansas' Department of Agricultural Economics and Agribusiness (AEAB) develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climatic conditions. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 presents a summary of 2015 costs and returns for Arkansas dry-seeded, delayed-flood conventional rice. Costs are presented on a per acre basis and with an assumed 1,000 acres. Program flexibility allows users to change total acres, as well as other variables to represent unique farm situations. Returns to total specified expenses are $284.47/acre. The budget program includes similar capabilities for Clearfield, hybrid, Clearfield hybrid, and water-seeded rice production.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an actual production history (APH) yield of 162.0/acre and an assumed projected price of $5.70/bu, input costs could be insured at selected coverage levels greater than 47%. Production expenses represent what is commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 53%. Total specified expenses could be insured at coverage levels of 80%.

SIGNIFICANCE OF FINDINGS

The crop enterprise budget program has a state level component that develops base budgets. County extension faculty can utilize base budgets as a guide to developing budgets that are specific to their respective counties, as well as customized budgets for individual producers. A county delivery system for crop enterprise budgets is consistent with the mission and organizational structure of the Arkansas Cooperative Extension Service.

The benefits provided by the economic analysis of alternative rice production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements. Flexible crop enterprise budgets are useful for planning that determines production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

ACKNOWLEDGMENTS

This research is made possible by funding from the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Edwards, W. 2005. Estimating Farm Machinery Costs. Iowa State University, University Extension, Ames, Iowa.

Givan, W. 1991. Using Machinery Costs to Make Decisions, AG ECON 91-003, Cooperative Extension Service, Extension Agricultural Economics, The University of Georgia, Athens, Ga.

Iron Solutions. 2014. “Iron Guides,” SE Region, Fall Issue, Franklin, Tenn.

Kay, R.D. and W.M. Edwards. 1999. Farm Management, Fourth Edition. WCB/McGraw-Hill, Boston, Mass.

Lazarus, W.F. and R.A. Selly. 2002. Suggested Procedures for Estimating Farm Machinery. Staff Paper P02-16, Department of Applied Economics, College of Agricultural, Food, and Environmental Sciences, University of Minnesota, Minneapolis-St. Paul, Minn.

USDA-NASS. U.S. Department of Agriculture, National Agricultural Statistics Service. 2014. Farm Labor. Washington, D.C.

Table 1. Summary of 2015 revenue and expenses, conventional rice, per acre and per 1,000 acres.

Summary of revenue and expenses			Crop insurance information	
Revenue	Per acre	Farm		Per acre
Acres	1	1,000		
Yield (bu)	180.0	180,000	APH[a] yield	162.0
Price ($/bu)	5.70	5.70	Projected price	5.70
Grower share	100%	100%		
Total crop revenue	**1,026.00**	**1,026,000**	**Revenue**	**923.40**
Expenses			**Percent of revenue**	(%)
Seed	33.84	33,840		4
Fertilizers and nutrients	132.70	132,700		14
Chemicals	90.13	90,133		10
Custom applications	44.10	44,100		5
Diesel fuel, field activities	28.73	28,729		3
Irrigation energy costs	100.99	100,987		11
Other inputs	5.15	5,150		1
Input costs	**435.64**	**435,638**		**47**
Fees	0.00	0		0
Crop insurance	0.00	0		0
Repairs and maintenance, includes employee labor	36.97	36,974		4
Labor, field activities	14.61	14,610		2
Production expenses	**487.22**	**487,222**		**53**
Interest	11.57	11,572		1
Post-harvest expenses	**119.43**	**119,430**		**13**
Custom harvest	0.00	0		
Total operating expenses	**618.22**	**618,223**		
Returns to operating expenses	**407.78**	**407,777**		
Cash land rent	0.00	0		0
Capital recovery and fixed costs	123.31	123,306		13
Total specified expenses	**741.53**	**741,530**		
Returns to specified expenses	**284.47**	**284,470**		

[a] APH = actual production history.

An Overview of Federal Crop Insurance Corporation (FCIC) Programs for Rice Producers in Arkansas, 2011 to 2014

R.U. Mane and K.B. Watkins

ABSTRACT

The Federal Crop Insurance Corporation (FCIC) programs that are administered by the Risk Management Agency (RMA) provide crop insurance to Arkansas rice producers. The objective of the federal crop insurance program is to help rice producers manage yield and price risk with different crop insurance products. Rice producers need to know more about the crop insurance programs so they can make informed choices about which crop insurance products and what level of coverage they should choose based on their needs. This study analyzes 4 years (2011 to 2014) of data on different crop insurance products used by Arkansas rice producers. Since 2011, rice revenue protection policies have grown from 38% of all rice policies in 2011 to 49% of all rice policies in 2014. In contrast, catastrophic policies have declined from 49% of all rice policies in 2011 to 29% of all rice policies in 2014. Most buy-up coverage for rice revenue protection falls in the 65% to 75% range, with the largest portion of revenue protection policies at the 70% revenue coverage level.

INTRODUCTION

Arkansas rice producers manage yield and price risk in production and marketing using different risk management tools. Federal crop insurance programs are one tool used by rice producers to manage yield and price risk. The federal crop insurance programs are administered by the Risk Management Agency (RMA) of the United States Department of Agriculture (USDA). In 2014, 1.2 million rice acres in Arkansas were insured under different federal crop insurance programs with a total indemnity value of 28.8 million dollars (USDA, RMA, 2015). Buy-up crop insurance participation for rice in Arkansas is less than that for crops in other regions due to 100% irrigation for rice (Anderson et al., 2013). The US Farm bill of 2014 places more emphasis on the use of crop insurance programs to manage price and yield risk rather than relying on historically unpopular farm programs like direct payments. Therefore there is a need for producers to have a good understanding of different crop insurance programs so they can make informed decisions in choosing different risk management tools offered by the Federal Crop Insurance Corporation (FCIC). The purpose of the study is to quantify the types of crop insurance products used by Arkansas rice producers for the period 2011 to 2014 using FCIC data.

Crop insurance products for rice fall into three general categories, catastrophic (CAT), yield protection (YP), and revenue protection (RP). Catastrophic insurance is a low-cost, minimum level disaster policy that insures the crop for 50% of the actual production history (APH) yield and 55% of the projected price (Edwards, 2011). The projected price for rice is the Chicago Board of Trade (CBOT) contract price for the period 15 January through 14 February. Yield protection insurance protects yields at varying buy-up coverage levels ranging from 50% to 85% of the APH yield. If the actual yield falls below the guaranteed yield (the APH yield multiplied by the coverage level), an indemnity payment is generated equal to the yield difference multiplied by the projected price (Edwards, 2011). Revenue protection insurance guarantees a certain level of revenue rather than yield. The revenue guarantee is equal to the higher of the projected price or harvest price multiplied by APH yield and the buy-up coverage level chosen (Edwards, 2014b). The harvest price for rice is equal to the CBOT contract price for rice for the period 1 September through 30 September. Buy-up coverage levels for RP (as with YP) range from 50% to 85%.

Catastrophic policies are 100% subsidized by the government, meaning producers pay no premiums for CAT coverage. Producers are only required to pay a $300 administrative fee for CAT. Producers must pay premiums for YP and RP insurance, and these premiums increase for higher buy-up coverage levels. Premiums paid by producers are government subsidized with the amount of the subsidy depending on the insurance unit purchased. Rice producers typically purchase either enterprise or optional crop insurance units. Enterprise units combine all acres of a single crop within a county into a single unit. Optional units allow the producer to break areas of coverage into owned and cash rented land, crop shared land, irrigated land, and dryland land. Enterprise units have higher subsidized premiums relative to optional units, meaning the producer paid premiums are smaller for enterprise units. Table 1 presents the different premium subsidy rates for enterprise and optional units by coverage level.

PROCEDURES

The study uses FCIC rice crop insurance data for the period 2011 to 2014. Comparisons of the three different individual crop insurance products are made with respect to coverage, premium, and indemnities across the 4-year period. The results are presented in two ways. First, cumulative data are presented by insurance product (RP, YP, and CAT) over the 4-year period. The number of policies, the net acres covered, and the total value of indemnities are presented for each insurance product classification. Second, the number of insurance policies, per-acre producer premiums, and per-acre indemnities are presented for RP and YP rice insurance by buy-up coverage level.

RESULTS AND DISCUSSION

Rice crop insurance statistics are presented by insurance product (RP, YP, and CAT) for 2011 through 2014 in Table 2. The total net acres covered by the three crop insurance products in Table 2 (from 885 thousand acres in 2012 to 1.2 million acres in 2014) indicate that the majority of acres planted to rice in Arkansas are covered by some form of crop insurance. For example, the number of acres covered by crop insurance in 2013 (1.007 million acres) represents 94% of the total acres planted to rice in that year (1.076 million acres, USDA-NASS, 2014).

Catastrophic coverage accounted for the largest number of policies and covered acres in 2011, followed by revenue protection. However, revenue protection trended upward in both the number of policies and the number of acres covered during the 2011 to 2014 period, while CAT coverage trended downward during the same period. Yield protection accounted for the smallest number of policies and acres covered in all 4 years.

Total value of indemnities across insurance products were greatest in 2013 and 2011 ($63.7 and $62.2 million for 2013 and 2011, respectively) and smallest across insurance products for 2012 ($3.2 million). The year 2012 was extremely dry and resulted in large indemnities paid out in other regions of the U.S. due to drought. Rice is 100% irrigated, and fared well in 2012 relative to crops grown in other regions. Most of the indemnities paid out for rice in 2011, 2013, and 2014 were the result of prevented plantings resulting from excessive precipitation. Also, the value of total indemnities for each year is small relative to the value of rice production for each year. For example, the total value of indemnities in 2013 of $63.7 million represents only 5% of the total value generated for rice production in Arkansas in 2013, which was $1.253 billion (USDA-NASS, 2014). The value of indemnities ranged from 0.2% of total rice production value in 2012 to 6% of total rice production value in 2011. Thus, most rice producers purchasing crop insurance received no indemnities during any of the 4 years evaluated in this analysis.

The number of rice insurance policies for both RP and YP insurance are presented by buy-up coverage level in Table 3. The majority of rice RP policies fall in buy-up coverage levels between 65% and 75% in all 4 years, with the largest number of RP policies in the 70% buy-up coverage level. A large portion of rice RP policies are in the 50% buy-up coverage level also. Significantly less rice YP policies fall in the higher buy-up coverage levels. The majority of YP policies have 50% buy-up coverage for all 4 years. The fact that rice is 100% irrigated likely explains why rice producers purchase few YP policies at buy-up coverage levels above 50%.

Producer premiums paid per acre for both RP and YP insurance are presented by buy-up coverage level in Table 4. Producer premiums are total premiums net of the premium subsidies paid by the government. Per-acre producer premiums increase for higher coverage levels, with the most expensive premiums occurring for the highest buy-up coverage levels. There appears to be little difference in producer premiums between RP and YP for a given coverage level. This may also explain why there are more RP policies relative to YP policies at the 65% to 75% buy-up coverage levels for rice.

Per-acre indemnities are presented for rice RP and YP insurance by buy-up coverage level in Table 5. The largest indemnities per acre are paid out at the higher buy-up coverage levels for RP insurance, while the largest indemnities tend to be scattered across all coverage levels for YP insurance. The year 2012 had the smallest per-acre indemnities, implying 2012 was a good production year for rice relative to the other 3 years.

Per-acre net indemnities are presented for rice RP and YP insurance by buy-up coverage level in Table 6. Net indemnities are equal to total per-acre indemnities reported in Table 4 less producer premiums in Table 5. Net indemnities were positive for all buy-up coverage levels for the years 2011, 2013, and 2014. However, the positive net premiums reported in Table 6 do not mean that all rice producers purchasing either RP or YP insurance earned positive net indemnities during these 3 years. These numbers reflect average net indemnities, and many rice producers purchasing crop insurance likely received no indemnity payments in any of these 3 years. Also, 2012 demonstrates that crop insurance is purchased for a specific reason, namely to protect rice producers from yield and price risk. Net indemnities in 2012 were negative for both RP and YP insurance across most buy-up coverage levels, implying 2012 was a good production year for rice and few indemnities were paid out that year relative to the other three years.

SIGNIFICANCE OF FINDINGS

Arkansas rice producers insured the majority of planted rice acres during the years 2011 through 2014. However, the mix in insurance products changed from mostly catastrophic coverage in 2011 to mostly revenue protection in 2014. The availability of higher premium subsidies for enterprise units relative to optional units may have led to producers buying up more revenue protection during this period of time. Rice producers purchased less yield protection insurance products relative to revenue protection during all 4 years, reflecting the fact that yield risk is small for rice production due to irrigation. The value of total indemnities as a percent of total rice production value was small for all 4 years, ranging from 0.2% in 2012 to 6% in 2011, implying that many rice producers purchasing crop insurance received no indemnity payments during the 4-year period. Indemnity payments are less likely to cover cost of premium when yield and/or prices are high as witnessed in 2012. We can conclude that rice producers choose YP and RP policies based on premium subsidy and coverage level. There is a need to evaluate effectiveness of FCIC programs for rice with respect to cost of premium and indemnity payments using historical data.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Anderson J., R. Young, and T.D. Davis. 2013. Institutional barriers to an insurance based farm safety net. Paper presented at Agricultural and Applied Economics Associations 2013 Crop Insurance and the Farm Bill Symposium, Louisville, Ky.

Edwards, W. 2011. Yield protection crop insurance. Iowa State University, University Extension. Ag Decision Maker File A1-52. February 2011.

Edwards, W. 2014a. Proven yields and insurance units for crop insurance. Iowa State University, University Extension. Ag Decision Maker File A1-55.

Edwards, W. 2014b. Revenue protection crop insurance. Iowa State University, University Extension. Ag Decision Maker File A1-54.

USDA-NASS. U.S. Department of Agriculture, National Agricultural Statistics Service. 2014. Rice: acreage, yield, production, price and value. Delta Regional Office: Ark.

USDA-RMA. U.S. Department of Agriculture, Risk Management Agency, 2015. Federal Crop Insurance Corporation, Commodity Year Statistics for 2011 through 2014. Accessed 5 January, 2015. Available at: http://www3.rma.usda.gov/apps/sob/current_week/stcrop2014.pdf

Table 1. Premium subsidy rates by coverage level and crop insurance unit.[a]

Coverage level[b]	Optional unit premium subsidy	Enterprise unit premium subsidy
	(%)	
50	67	80
55	64	80
60	64	80
65	59	80
70	59	80
75	55	77
80	48	68
85	38	56

[a] Source: Edwards, W. 2014a. Proven Yields and Insurance Units for Crop Insurance. Iowa State University, University Extension. Ag Decision Maker File A1-55. September 2014.

[b] Buy-up coverage for either yield protection (YP) or revenue protection (RP) crop insurance.

Table 2. Arkansas rice crop insurance statistics by insurance product, 2011–2014.[a]

Insurance product	2011		2012		2013		2014	
	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
	---Rice crop insurance policies earning premiums---							
Revenue protection (RP)	1,400	38	1,310	36	1,574	42	2,120	49
Yield protection (YP)	649	18	824	23	837	22	1,038	24
Catastrophic (CAT)	1,651	45	1,501	41	1,350	36	1,209	28
Total	3,700	100	3,635	100	3,761	100	4,367	100
	---Rice net acres covered by crop insurance policies---							
Revenue protection (RP)	418,902	42	340,809	39	457,822	45	638,001	52
Yield protection (YP)	91,500	9	121,930	14	170,842	17	227,695	19
Catastrophic (CAT)	491,687	49	422,286	48	378,443	38	352,556	29
Total	1,002,089	100	885,025	100	1,007,107	100	1,218,252	100
	---Total value of indemnities for rice in dollars by insurance plan---							
Revenue protection (RP)	47,162,055	76	2,694,977	84	47,550,163	75	23,395,750	81
Yield protection (YP)	8,889,856	14	441,063	14	11,711,098	18	4,376,736	15
Catastrophic (CAT)	6,105,787	10	72,443	2	4,459,404	7	1,091,022	4
Total	62,157,698	100	3,208,483	100	63,720,665	100	28,863,508	100

[a] Source: Federal Crop Insurance Corporation, Summary of Business Statistics.

Table 3. Number of Arkansas rice revenue protection and yield protection policies earning premiums by coverage level 2011–2014.[a]

Coverage level	2011		2012		2013		2014	
(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
	---Revenue protection policies earning premiums---							
50	175	13	177	14	233	15	301	14
55	36	3	27	2	34	2	43	2
60	79	6	77	6	86	5	104	5
65	204	15	176	13	191	12	221	10
70	525	38	509	39	616	39	767	36
75	276	20	286	22	318	20	522	25
80	97	7	50	4	82	5	119	6
85	8	1	8	1	14	1	43	2
Total	1,400	100	1,310	100	1,574	100	2,120	100
	---Yield protection policies earning premiums---							
50	457	70	484	59	532	64	634	61
55	19	3	33	4	25	3	33	3
60	33	5	40	5	40	5	56	5
65	70	11	82	10	77	9	86	8
70	47	7	117	14	107	13	144	14
75	17	3	28	3	24	3	46	4
80	6	1	40	5	32	4	37	4
85	0	0	0	0	0	0	2	0
Total	649	100	824	100	837	100	1,038	100

[a] Source: Federal Crop Insurance Corporation, Summary of Business Statistics.

Table 4. Producer paid premiums per acre by insurance product and coverage level, Arkansas rice, 2011–2014.[a]

	Revenue protection				Yield protection			
Coverage Level	2011	2012	2013	2014	2011	2012	2013	2014
(%)								
50	5.63	5.87	7.16	8.96	5.25	4.51	5.40	6.72
55	5.36	6.22	8.21	8.86	7.29	6.39	5.45	8.51
60	7.86	7.88	8.24	9.05	7.93	10.11	12.03	9.58
65	11.11	9.76	9.92	10.66	9.86	9.35	9.14	13.16
70	12.85	10.72	11.74	11.76	11.14	11.51	12.39	11.81
75	17.26	15.06	16.45	15.23	20.92	12.48	18.03	16.88
80	41.56	31.57	29.78	25.16	33.68	22.07	24.03	22.71
85	65.30	48.98	34.97	40.49	---	---	---	15.65

[a] Source: Derived from data obtained from the Federal Crop Insurance Corporation, Summary of Business Statistics.

Table 5. Indemnities paid out per acre by insurance product and coverage level, Arkansas rice, 2011–2014.[a]

	Revenue protection				Yield protection			
Coverage Level	2011	2012	2013	2014	2011	2012	2013	2014
(%)								
50	42.30	2.78	43.70	18.73	84.16	1.38	42.28	10.54
55	56.00	1.35	19.32	9.78	110.59	11.20	55.21	15.91
60	65.20	1.63	70.15	14.51	103.13	6.73	163.85	19.42
65	85.10	8.58	66.49	17.55	60.90	8.46	61.40	15.02
70	122.87	3.62	114.71	34.71	121.03	3.99	91.00	26.13
75	131.85	4.42	127.10	41.96	264.35	7.45	180.07	96.75
80	181.24	72.12	189.02	52.82	231.24	3.10	109.85	50.07
85	428.37	317.85	87.12	122.35	---	---	---	142.53

[a] Source: Derived from data obtained from the Federal Crop Insurance Corporation, Summary of Business Statistics.

Table 6. Net indemnities paid out per acre by insurance product and coverage level, Arkansas rice, 2011–2014.[a]

	Revenue protection				Yield protection			
Coverage Level	2011	2012	2013	2014	2011	2012	2013	2014
(%)								
50	36.68	-3.09	36.54	9.78	78.91	-3.13	36.88	3.81
55	50.64	-4.88	11.11	0.91	103.30	4.81	49.76	7.40
60	57.34	-6.24	61.91	5.46	95.20	-3.38	151.82	9.84
65	73.99	-1.18	56.56	6.89	51.05	-0.89	52.27	1.86
70	110.03	-7.0	102.97	22.95	109.90	-7.52	78.61	14.31
75	114.59	-10.64	110.65	26.73	243.42	-5.03	162.04	79.87
80	139.67	40.55	159.24	27.66	197.56	-18.97	85.81	27.36
85	363.07	268.87	52.15	81.86	---	---	---	126.88

[a] Source: Derived from data obtained from the Federal Crop Insurance Corporation, Summary of Business Statistics.

ECONOMICS

World and U.S. Rice Outlook: Deterministic and Stochastic Baseline Projections, 2014-2024

E.J. Wailes and E.C. Chavez

ABSTRACT

Projections over the next decade indicate steady growth in global rice trade, as export shipments expand in Thailand, Cambodia, Vietnam, and Myanmar; and imports grow strongly in the Western African countries and the Middle East. The U.S remains one of the top five rice exporters in the world as it exports nearly half of its total rice output. Global rice production growth will come mainly from yield improvements with area harvested increasing only marginally. The world is projected to face abundant rice supplies due to current surpluses; increased productivity and use of modern growing and processing technologies; and increased focus on self-sufficiency in rice. Population drives consumption growth as per capita use declines slightly. There are typical risks involved in the rice industry, i.e., market outcomes can vary due to the uncertainties of weather, domestic policies, political developments, and other unexpected events. Hence a stochastic analysis which indicates the probable upper and lower bounds (confidence intervals) of future possible distribution of outcomes is included in this report.

INTRODUCTION

This outlook contains baseline rice projections from the Arkansas Global Rice Economics Program (AGREP) under the Department of Agricultural Economics and Agribusiness at the University of Arkansas in Fayetteville for global rice economies. The purpose of this document is not to predict but to present the current state and the expected directions of the rice economies in the world over the next decade by assessing their potential supply and demand paths as well as the degree of variability on some of the key variables.

Over the last 3 years, the global rice market has been dominated by two key events: India's official lifting of its ban on non-basmati rice exports and Thailand's implementation of its controversial and costly paddy pledging program (PPP), a price-floor support policy for Thai farmers (Wailes and Chavez, 2013). As a result of PPP, Thailand lost its trade leadership as its prices became uncompetitive with other Asian exporters; its stockpiles doubled; and the Thai price lost its usefulness as a global reference price. However, following the May 2014 coup, the PPP was suspended by the new military government and replaced with subsidized credit and inputs to farmers (USA Rice Federation, 2014); and a limited pledging program for fragrant and glutinous rice was implemented (USDA-FAS, 2014). This resulted in the Thai price becoming more globally competitive once again; and regaining its role as a useful reference price.

PROCEDURES

The deterministic and stochastic baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework that covers 51 rice-producing and rice-consuming countries/regions developed and maintained by AGREP.

Other details and the theoretical structure and the general equations of the AGRM can be found in the online documentation by Wailes and Chavez (2011). The historical rice data comes from USDA-FAS (2015) and USDA-ERS (2015); and the macro data comes from IHS Global Insight through FAPRI-Missouri. The baseline projections are grounded in a series of assumptions as of January 2015 about the general economy, agricultural policies, weather, and technological change. The basic assumptions include the following: continuation of existing policies; current macroeconomic variables; no new World Trade Organization trade reforms; and average, normal weather conditions. In light of the historical volatility of the global rice economy, a stochastic analysis is included in this report to provide a better understanding of the probable distribution of future outcomes.

RESULTS AND DISCUSSION[1]

Deterministic Analysis

Over the next decade, growth in global domestic use is projected to exceed domestic supply slightly as countries replenish stocks and total rice trade expands by 1.4%/year resulting in steady gain of 1.1% in long-grain international prices. Despite rhetoric on the contrary, there are indications that main rice-deficit countries are becoming more attuned to imports to improve food security. The average long-grain rice

---

[1] Although complete baseline projections for supply and demand variables are generated for all 50 countries/regions covered by AGRM, only selected variables are included in this report due to space consideration.

international reference price increases from $426/metric ton (mt) in 2014 to $485/mt in 2024. Over the same period, international medium-grain rice prices are projected to sustain a relatively high level, ranging from $815 to $875/mt (Table 1), as segmentation increase in trade flows and prices of long- and medium-grain markets.

While Thai prices have converged with international market prices recently, the Western Hemisphere (WH) prices remain abnormally high—with margins to Asian prices as high as $200/mt, an unsustainable level. Over the projection period, the margin declines to a more historically consistent level of about $51/mt as WH prices decline and Asian prices increase steadily (Table 1)—making U.S. exports relatively more competitive. Rigidity in moving the margin narrower is based on negotiated preferences for U.S. rice in bilateral and regional trade agreements. United States rice average farm prices are projected to follow the declining trend (Table 2).

Over the projection period, India and People's Republic of China (PRC) will continue to account for the bulk of the global rice economy. The two countries are projected to account for 25.6% of the growth in total global population, with a combined share in world population of 35.3% by 2024. They will have a combined share of 45.2% of world area harvested, 51.2% of total milled rice production, 50.0% of total rice consumption, and 69.5% of world rice ending stocks.

Rice output is projected to expand over the next decade, driven by the use of higher-yielding varieties and hybrids and other improved production technologies—in line with more focused self-sufficiency programs of major consuming countries. World production grows at 0.93%/year, reaching 528.1 million metric tons (mmt) in 2024 with 0.80% coming from yield improvement and 0.13% coming from growth in area harvested (Table 3). By volume, 26.5% of the expected growth will come from India; 44.3% from the seven countries of Bangladesh, Indonesia, Myanmar, PRC, Thailand, Cambodia, and Vietnam combined; and 9.4% from the Economic Community of West African States (ECOWAS). Total U.S. rice production is projected to increase by about 1.35 mmt (or 43.4 mil. cwt) over the same period, equivalent to 1.8% annual growth—with 1.1% attributed to area harvested and 0.7% to yield (Table 2).

Rice consumption is driven by income, population, and other demographic variables. Rising incomes dampen rice demand in some Asian countries where rice is considered an inferior good. Demographic trends also weaken rice demand as aging populations and increasing health consciousness shift preferences away from carbohydrates and towards protein-based diets.

Over the baseline, global rice consumption is projected to increase by 47.9 mmt reaching 526.1 mmt in 2024—a growth of 0.87%/year, with population growth of 1.01%/year projected to be offset partly by a 0.14% decline in average world rice per capita use (Table 3).

About 28% of the total growth is accounted for by India; 27.1% by the four countries of Bangladesh, Indonesia, the Philippines, and Myanmar combined; and 16.6% by ECOWAS. United States rice total consumption increases by nearly 582 thousand metric tons (tmt; 18.2 mil. cwt) over the same period, reaching 4.6 million metric tons (mmt; 143.2 mil. cwt) in 2024 or an annual growth of 1.24%, of which 0.49% comes from per capita use and 0.75% from population. Global stocks-to-use ratio increases from 21.8 in 2014 to 24.7 in 2024, due mainly to PRC's 25-mmt stocks build up from 2014 to 2024.

Total global rice trade expands from 41.7 mmt in 2014/15 to 49.4 mmt in 2024 (Table 1). On the exporters' side, the significant investment in production and processing capacity in Mekong Delta in Vietnam, Cambodia, and Myanmar bodes well for these countries' increasing role as major rice suppliers in the coming years. As low-cost producers, these countries are well-poised geographically to supply the steady China market. The productivity gains from hybrids and Global Rice Science Partnership (i.e., GRiSP) research are expected to have positive impacts on Asian and African rice economies.

Despite Thailand's costly, unpopular, and controversial paddy pledging program, the country is projected to resume its strong presence in the global rice market over the next decade—given its good infrastructural resources and concerted focus on developing and maintaining a strong presence in the branded high quality rice. While the government reportedly plans to liquidate the PPP stocks over the next 3 years, it seems relatively cautious in releasing the PPP rice stocks into the market to avoid depressing the prices (USDA-FAS, 2014). For the U.S., total rice exports expand by 735 tmt and remain in the range of 3.3 to 3.7 mmt; and total imports grow by 148 tmt, resulting in expansion in net trade of 587 tmt. For reference purposes, a detailed U.S. rice supply and use in English units is presented in Table 2. Cambodia's exports are projected to expand steadily and double from 1.2 mmt in 2014 to 2.4 mmt in 2024 as yield-based production growth exceeds that of consumption; whereas Myanmar's exports are projected to expand from 1.5 mmt to 2.7 mmt.

Global rice imports are projected to expand by 7.1 mmt over the same period (2014-2024), equivalent to an annual growth of 1.4%. While PRC remains an important major rice importer over the next decade, 77% of the growth in imports will come from Africa and18% from the Middle East. The 15-member ECOWAS[2] accounts for 62% of the growth in African imports. In general, expansion in imports is associated with a combination of lagging production relative to consumption and population growth.

Stochastic Analysis

The detailed results of the stochastic analyses for selected prices and trade are presented in Figures 1 through 8. In order to show the direction and dispersion of the stochastic outcome distribution, four selected outcome items [stochastic average, 10th percentile, 90th percentile, and the coefficient of variation (CV)] for selected variables are presented. Intuitively, the gap between the two percentiles (10th and 90th) indicates volatility or risk. Widening indicates increased volatility and narrowing indicates decreased volatility. Another measure of dispersion used is the CV which shows the extent of variability of data points in relation to the mean. Lower CV indicates more stability, i.e., less risk. The information projected in each one of the charts is similar in

[2] ECOWAS' 15-member countries include Cote D'Ivoire, Ghana, Guinea, Liberia, Mali, Nigeria, Senegal, Sierra Leone, Benin, Burkina-Faso, Gambia, Guinea-Bissau, Niger, Togo, and Cabo Verde.

principle. Hence, for space consideration only one representative chart (Fig. 1) will be discussed—which can then be used as a pattern in understanding the rest of the charts. Figure 1 shows the long-grain rice international reference price. For 2015, while the deterministic mean price is $433/mt (Table 1), the stochastic distribution indicates that 10% of the time the average price will be higher than $535/mt and lower than $364/mt 10% of the time. The computed CV for 2015 is 15.3%. This feature of the stochastic analysis provides an advantage as it indicates how the possible outcomes are distributed, thus providing a better understanding of the dynamics of the global rice market.

SIGNIFICANCE OF FINDINGS

Understanding the market and policy forces that drive the global rice market are beneficial for Arkansas rice stakeholders. This is especially true because Arkansas is the top rice-producing state in the U.S. accounting for 45% to 50% of the country's rice output; and nearly half of the Arkansas annual rice crop is exported. Market prices received by Arkansas rice producers are primarily determined by the factors that affect international trade. These include changes in rice production and consumption patterns, the economics of alternative crops, domestic and international rice trade policies, as well as the general macroeconomic environment in which global rice trade is transacted. The baseline results presented in this report can be considered as a synthesis of the impacts of these factors, and serve to indicate what could happen over the next decade. The estimates are intended for use by government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders who conduct medium- and long-term planning.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas rice farmers who provided support through the rice check-off funds administered by the Rice Research and Promotion Board, which provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model. The model was updated twice in 2014 and once in January 2015 in collaboration with FAPRI-Missouri which provided the bulk of the funds for the global rice modeling program.

LITERATURE CITED

USA Rice Federation. 2014. Comments Regarding the 2015 National Trade Estimate Report on Foreign Trade Barriers. 28 October 2014. Available at: http://www.usarice.com/doclib/193/186/7767.pdf

USDA-ERS. 2015. Rice Outlook. RCS-15A (by Nathan Childs), 14 January 2015. Available at: http://www.ers.usda.gov/media/1736964/rcs-15a.pdf

USDA-FAS. 2014. Thailand Grain and Feed Update, October 2014. Gain Report No. TH4104.

USDA-FAS. 2015. Production, Supply, and Distribution (PSD). Accessed 14 January 2015. Available at: http://apps.fas.usda.gov/psdonline/psdQuery.aspx

Wailes, E.J. and E.C. Chavez. 2011. 2011 Updated Arkansas Global Rice Model. University of Arkansas Department of Agricultural Economics and Agribusiness, Division of Agriculture Staff Paper 2011-01. Accessed 25 March 2015. Available at: http://ageconsearch.umn.edu/handle/102650

Wailes, E.J. and E.C. Chavez. 2013. World rice outlook: International rice baseline projections, 2012-2022. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012 University of Arkansas Agricultural Experiment Station, Research Series 609:401-417. Fayetteville, Ark.

Table 1. World rice total trade by country and international reference prices, 2013-2024.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	(1000 metric tons)											
EXPORTERS												
United States	2985	3284	3334	3584	3639	3622	3621	3635	3636	3659	3678	3720
Thailand	10300	10708	11158	11335	11559	11815	12095	12374	12623	12894	13195	13579
Pakistan	3900	3973	4001	4013	4035	4028	4067	4085	4098	4127	4132	4151
Myanmar	1550	1549	1478	1552	1580	1719	1973	2211	2434	2550	2655	2712
Vietnam	6500	6578	7082	6971	7035	7095	7254	7261	7385	7587	7694	7776
People's Republic of China	257	417	487	589	648	676	679	709	735	741	770	781
India	10300	8582	7185	7038	7122	7244	7246	7314	7544	7694	8045	8064
Cambodia	1000	1183	1273	1367	1570	1771	1895	2008	2119	2240	2365	2422
Lao PDR	-15	-10	33	57	65	78	91	106	121	145	166	194
Australia	460	402	417	431	440	452	477	502	515	528	535	538
Egypt	600	501	504	673	669	695	715	735	751	759	763	766
Turkey	20	20	20	20	20	20	20	20	20	20	20	20
European Union 28	245	331	338	341	344	347	352	368	374	355	338	387
Brazil	900	898	879	892	890	887	890	889	889	889	889	889
Cote d'Ivoire	30	30	30	30	30	30	30	30	30	30	30	30
Senegal	10	10	10	10	10	10	10	10	10	10	10	10
Guinea	100	100	100	100	100	100	100	100	100	100	100	100
Tanzania	30	30	30	30	30	30	30	30	30	30	30	30
Japan	200	200	200	200	200	200	200	200	200	200	200	200
Argentina	600	595	629	652	641	670	656	658	677	685	693	707
Uruguay	890	967	1000	1032	1051	1071	1089	1106	1122	1136	1150	1147
ROW and Residual	1364	1357	1314	1290	1282	1269	1256	1241	1226	1202	1181	1153
Total Exports	42226	41705	41502	42205	42960	43830	44746	45594	46639	47582	48638	49377
IMPORTERS												
United States	733	712	771	766	781	778	795	803	814	827	852	881
Thailand	300	500	467	422	463	451	445	453	450	449	451	450
Pakistan	30	43	39	37	40	39	39	39	39	39	39	39
Vietnam	300	300	300	300	300	300	300	300	300	300	300	300

continued

Table 1. Continued.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	(1000 metric tons)											
IMPORTERS, continued												
People's Republic of China	4015	3998	3781	3773	3686	3701	3718	3731	3743	3756	3767	3782
China-Hong Kong	420	426	423	423	426	428	430	432	433	435	436	437
Egypt	25	25	25	25	25	25	25	25	25	25	25	25
Japan	654	682	682	682	682	682	682	682	682	682	682	682
Bangladesh	751	615	872	846	986	1012	819	620	378	223	128	84
Indonesia	1225	1368	1705	1910	1682	1599	1412	1270	1311	1376	1359	1315
Iraq	1350	1396	1412	1445	1491	1553	1598	1644	1697	1747	1796	1842
Iran	1650	1603	1605	1714	1782	1870	1899	1957	2006	2046	2104	2138
Malaysia	1100	1098	1049	1061	1092	1099	1135	1138	1157	1170	1196	1210
Philippines	1450	1469	1270	1246	1364	1471	1483	1570	1649	1752	1860	1981
Saudi Arabia	1450	1404	1457	1485	1518	1551	1585	1616	1645	1673	1701	1726
European Union 28	1530	1513	1503	1512	1535	1551	1572	1590	1608	1625	1642	1658
Singapore	300	304	308	312	317	319	322	325	327	329	331	332
Brunei Darussalam	60	44	44	46	46	48	48	49	50	51	53	53
Turkey	341	295	288	316	307	319	331	339	335	345	351	349
South Korea	310	409	409	409	409	409	409	409	409	409	409	409
Taiwan	135	126	126	126	126	126	126	126	126	126	126	126
Australia	150	152	151	151	150	148	147	147	147	147	147	147
Brazil	700	739	471	421	376	364	269	183	139	76	55	36
Mexico	693	779	757	771	790	810	829	850	878	886	887	908
Canada	377	381	386	391	404	413	423	431	440	448	457	465
Cote d'Ivoire	1150	1159	1186	1199	1199	1230	1245	1260	1273	1285	1300	1298
Nigeria	2800	3302	3254	3280	3381	3484	3673	3889	4086	4299	4550	4830
South Africa	975	1033	1034	1050	1069	1089	1114	1135	1159	1170	1178	1190
Senegal	1100	1140	1115	1131	1153	1185	1216	1249	1281	1316	1345	1379
Ghana	600	638	693	731	740	764	784	802	814	840	844	870
Cameroon	525	508	509	523	544	542	560	586	587	598	592	586
Mozambique	500	532	541	563	585	618	643	670	700	729	759	781
Guinea	340	325	305	299	289	262	262	269	269	277	288	315

continued

Table 1. Continued.

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	(1000 metric tons)											
IMPORTERS, continued.												
Kenya	430	387	419	427	440	447	474	502	522	553	583	605
Tanzania	200	208	157	113	96	92	103	105	138	160	212	234
Sierra Leone	270	222	205	196	176	158	153	151	154	141	135	139
Mali	150	51	17	-32	-16	-18	-7	2	1	-24	-42	-128
Liberia	300	301	302	295	300	307	314	324	334	342	356	369
Colombia	325	362	345	347	359	372	377	383	385	386	392	394
ROW and Residual	12512	11156	11118	11495	11865	12232	12992	13538	14145	14570	14994	15140
Total Imports	42226	41705	41502	42205	42960	43830	44746	45594	46639	47582	48638	49377
PRICES	(U.S. dollars/metric ton)											
International Rice Reference Price	428	426	433	455	457	465	469	473	475	478	479	485
U.S. FOB Gulf Ports	603	527	528	527	532	538	538	541	541	537	538	536
U.S. No. 2 Medium FOB CA[a]	816	875	849	818	826	815	822	831	834	825	829	832

[a] FOB CA = free on board, California.

Table 2. World rice supply and utilization and macro data, 2013-2024.

Country	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25
	(thousand metric tons)											
Area harvested	160,865	160,920	161,316	161,910	162,268	162,395	162,521	162,686	162,783	162,804	163,076	163,110
	(mt/ha)											
Yield	2.96	2.99	3.01	3.04	3.07	3.09	3.12	3.15	3.17	3.20	3.22	3.24
	(1000 mt)											
Production	476,960	481,031	485,460	492,798	498,335	502,293	506,810	511,660	516,527	520,994	525,281	528,072
Beginning stocks	110,095	107,067	105,159	105,552	108,056	111,050	113,633	115,813	118,146	121,051	124,159	127,747
Domestic supply	587,055	588,098	590,619	598,350	606,391	613,343	620,443	627,473	634,674	642,045	649,441	655,820
Consumption	478,200	483,033	485,162	490,396	495,444	499,821	504,763	509,486	513,794	518,072	521,885	526,094
Ending stocks	107,067	105,159	105,552	108,056	111,050	113,633	115,813	118,146	121,051	124,159	127,747	129,925
Domestic use	585,267	588,193	590,714	598,453	606,495	613,454	620,576	627,632	634,845	642,232	649,633	656,019
Total trade	42,226	41,705	41,502	42,205	42,960	43,830	44,746	45,594	46,639	47,582	48,638	49,377
	(kg)											
Per capita use	66.53	66.45	66.01	66.00	65.98	65.89	65.88	65.85	65.78	65.71	65.60	65.55
	(%)											
Stocks-to-use ratio	22.39	21.77	21.76	22.03	22.41	22.73	22.94	23.19	23.56	23.97	24.48	24.70
Population growth	1.15	1.14	1.12	1.10	1.07	1.04	1.01	0.99	0.96	0.94	0.91	0.89
Real GDP growth	2.58	2.65	2.99	3.38	3.53	3.59	3.68	3.76	3.69	3.59	3.52	3.45

Table 3. Detailed U.S. rice supply and utilization and macro data, 2013-2024.

Country	Units	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25
YIELD (rough basis)	(lb/acre)	7693.5	7572.3	7723.6	7802.7	7884.1	7958.2	8032.0	8102.4	8175.9	8250.4	8324.2	8398.5
Total harvested Area	(1000 acres)	2469.0	2919.0	2856.7	2860.5	2852.9	2853.4	2841.7	2820.6	2802.5	2790.0	2776.7	2778.5
SUPPLY (rough basis)	(mil. cwt[a])	249.5	275.1	285.0	293.7	293.8	293.0	292.8	292.7	292.5	293.4	294.4	297.3
Production	(mil. cwt)	190.0	221.0	220.6	223.2	224.9	227.1	228.2	228.5	229.1	230.2	231.1	233.3
Beginning stocks	(mil. cwt)	36.4	31.8	40.3	46.5	44.5	41.5	39.7	39.0	37.9	37.3	36.6	36.4
Imports	(mil. cwt)	23.1	22.3	24.1	24.0	24.4	24.3	24.9	25.1	25.5	25.9	26.7	27.5
DOMESTIC USE (rough basis)	(mil. cwt)	125.0	132.2	134.2	137.1	138.5	140.0	140.6	141.1	141.5	142.4	142.9	143.2
Food	(mil. cwt)	108.2	105.3	106.4	107.4	108.5	109.6	110.8	112.0	113.8	115.8	117.8	119.8
Seed	(mil. cwt)	3.6	3.6	3.6	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.5	3.5
Brewing	(mil. cwt)	18.2	18.7	18.9	19.0	19.1	19.2	19.4	19.5	19.6	19.8	19.9	20.0
Residual	(mil. cwt)	-5.1	4.5	5.4	7.2	7.4	7.6	6.9	6.1	4.5	3.3	1.7	-0.2
EXPORTS	(mil. cwt)	92.7	102.7	104.3	112.1	113.8	113.3	113.2	113.7	113.7	114.4	115.0	116.3
TOTAL USE	(mil. cwt)	217.6	234.9	238.5	249.2	252.3	253.2	253.8	254.7	255.2	256.8	257.9	259.5
ENDING STOCKS	(mil. cwt)	31.8	40.3	46.5	44.5	41.5	39.7	39.0	37.9	37.3	36.6	36.4	37.8
PRICES													
Loan Rate	(US$/cwt[b])	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Season ave. farm price	(US$/cwt)	16.10	14.15	13.65	13.64	13.75	13.90	13.92	13.97	13.96	13.87	13.88	13.86
Long-grain farm price	(US$/cwt)	15.40	12.32	12.25	12.21	12.28	12.41	12.43	12.48	12.46	12.37	12.37	12.34
Medium-grain farm price (Avg.)	(US$/cwt)	18.50	18.60	17.93	17.25	17.36	17.16	17.29	17.47	17.54	17.37	17.43	17.51
Japonica farm price	(US$/cwt)	19.90	21.74	18.65	18.58	18.69	18.88	18.90	18.97	18.94	18.81	18.81	18.78

continued

Table 3. Continued.

Country	Units	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25
PRICES, cont.													
Medium/short (excl. Japonica) farm price	(US$/cwt)	15.80	15.00	14.92	14.87	14.95	15.11	15.12	15.18	15.16	15.06	15.06	15.03
Reference prices:													
Long-grain farm price	(US$/cwt)	10.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Medium/short (excl. Japonica)	(US$/cwt)	10.50	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Japonica	(US$/cwt)	10.50	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Export price, FOB Houston (U.S. No. 2)	(US$/cwt)	27.35	23.89	23.94	23.89	24.11	24.38	24.42	24.53	24.52	24.36	24.38	24.33
Medium-grain Price, FOB CA (U.S. No. 2)	(US$/cwt)	37.01	39.70	38.52	37.11	37.48	36.96	37.30	37.69	37.85	37.43	37.62	37.74
Direct payment	(US$/cwt)	2.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Program payment	(US$/cwt)	0.00	1.21	1.25	1.26	1.20	1.09	1.08	1.04	1.05	1.10	1.10	1.10
Average world price	(US$/cwt)	11.84	11.22	11.40	11.60	11.73	11.96	12.09	12.20	12.28	12.33	12.41	12.50
INCOME FACTORS:													
Production market value	(mil. US$[c])	3104	3087	3041	3030	3074	3113	3139	3163	3173	3164	3182	3214
Contract payment + MLA	(mil. US$)	497	0	0	0	0	0	0	0	0	0	0	0
Marketing loan/certificates	(mil. US$)	0	0	0	0	0	0	0	0	0	0	0	0
Program payment	(mil. US$)	0	268	275	282	270	249	246	238	241	254	254	257
Total income	(mil. US$)	3601	3355	3316	3312	3344	3362	3385	3400	3414	3418	3436	3471

continued

Table 3. Continued.

Country	Units	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25
INCOME FACTORS, cont.													
Market returns above variable cost	(US$/ac)	657	551	560	567	576	582	576	495	481	471	468	463
Total returns above variable cost	(US$/ac)	838	642	656	666	671	669	663	495	481	471	468	463
Per capita use	(Kg)	12.62	13.25	13.35	13.54	13.56	13.61	13.56	13.51	13.44	13.43	13.38	13.31
Stocks-to-use ratio	(%)	14.63	17.15	19.51	17.84	16.47	15.68	15.37	14.88	14.63	14.24	14.12	14.57
Population growth	(%)	0.71	0.72	0.78	0.77	0.77	0.77	0.77	0.76	0.75	0.75	0.74	0.73
Real GDP growth	(%)	2.58	2.65	2.99	3.38	3.53	3.59	3.68	3.76	3.69	3.59	3.52	3.45

[a] mil cwt = million hundred weight.
[b] US$/cwt = United States dollars/hundred weight.
[c] mil. US$ = million United States dollars.

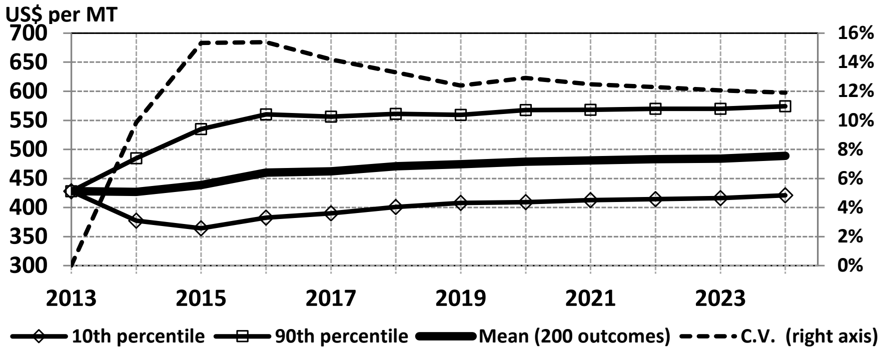


Fig. 1. Stochastic projections of long-grain rice international reference price, 2013-2024.

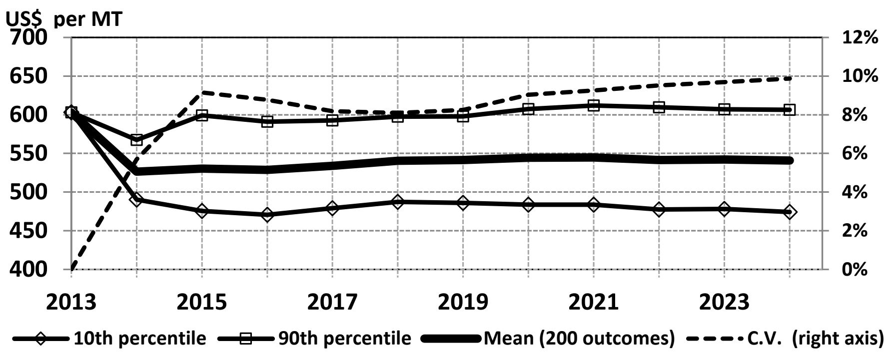


Fig. 2. Stochastic projections of U.S. long-grain rice free on board export price (U.S. dollars/metric ton), 2013-2024.

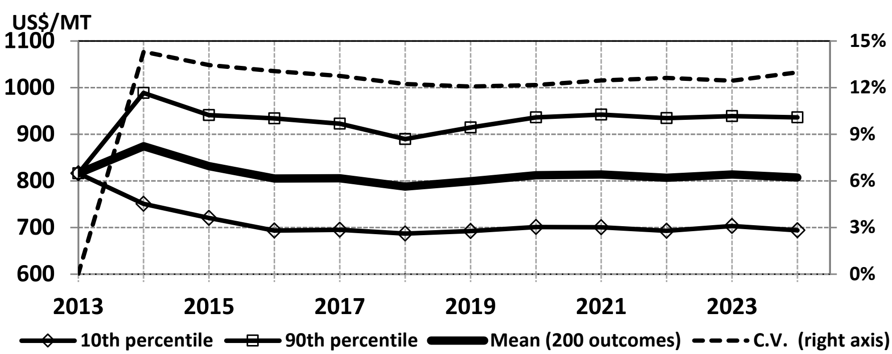


Fig. 3. Stochastic projections of medium-grain rice mill price, free on board California (U.S. dollars/metric ton), 2013-2024.

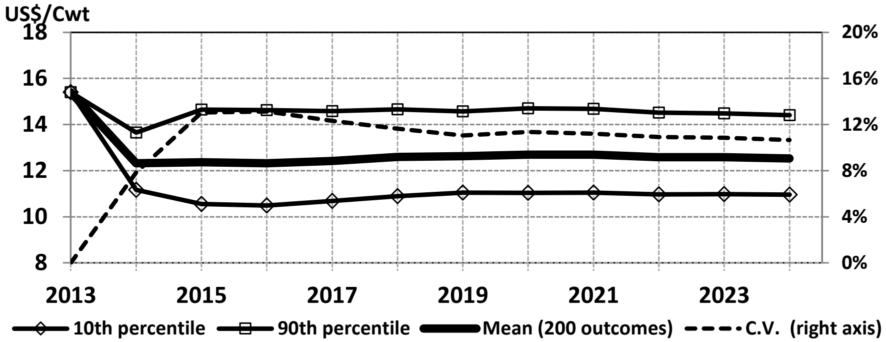


Fig. 4. Stochastic projections of U.S. long-grain average farm price [U.S. dollars/hundred weight (cwt)], 2013-2024.

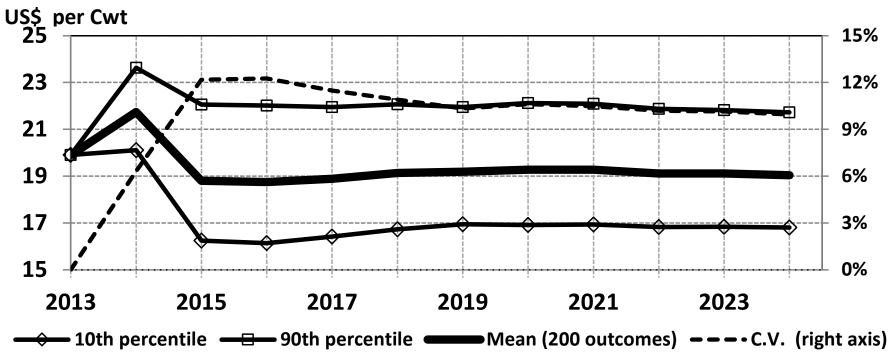


Fig. 5. Stochastic projections of U.S. Japonica average farm price [U.S. dollars/hundred weight (cwt)], 2013-2024.

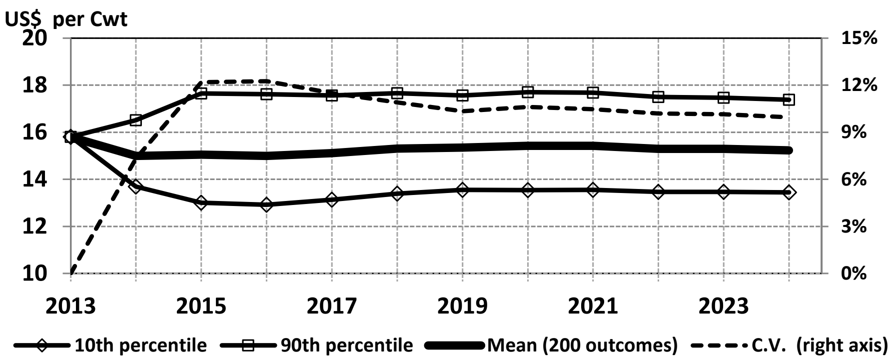


Fig. 6. Stochastic projections of U.S. medium-/small-grain (excluding Japonica) average farm price [U.S. dollars/hundred weight (cwt)], 2013-2024.

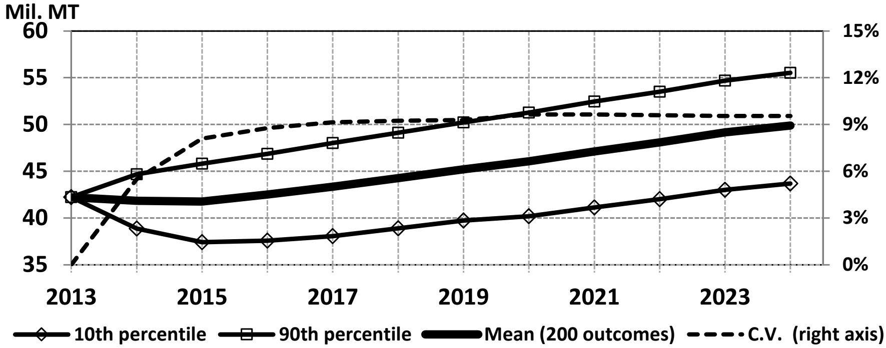


Fig. 7. Stochastic projections of world rice total trade (million metric tons), 2013-2024.

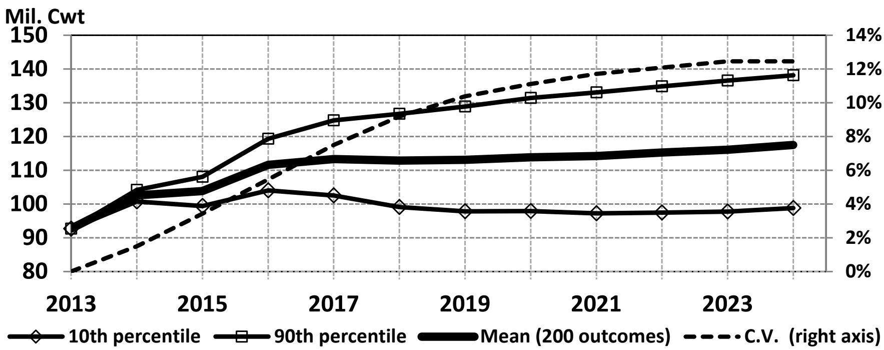


Fig. 8. Stochastic projections of U.S. rice total exports [million hundred weight (cwt)], 2013-2024.

NOTES

NOTES

NOTES

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

University of Arkansas System

B.R. Wells Arkansas Rice Research Studies 2014 Norman and Moldenhauer AAES